Northeastern Pacific Albacore Survey
Part 1. Biological Observations

SPECIAL SCIENTIFIC REPORT—FISHERIES NO. 310

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

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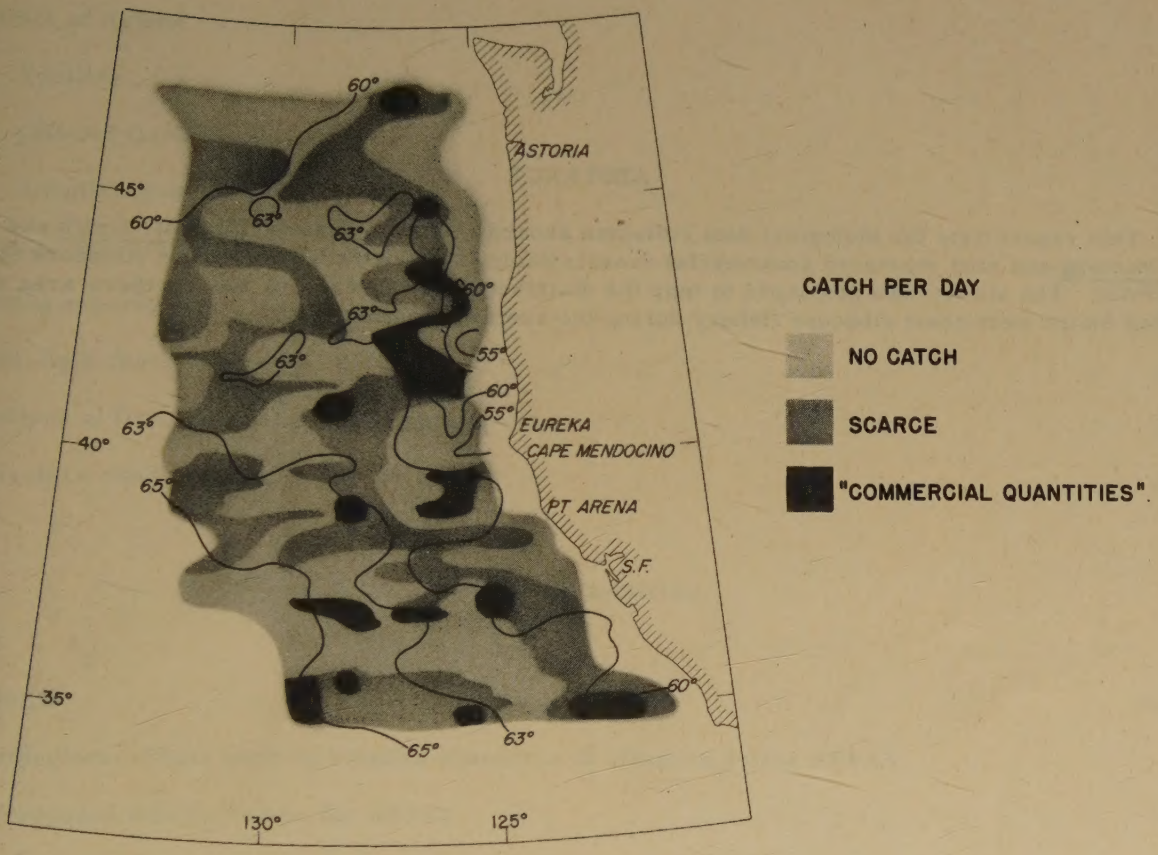

NORTHEASTERN PACIFIC ALBACORE SURVEY

PART 1. BIOLOGICAL OBSERVATIONS

By

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Special Scientific Report--Fisheries No. 310

WASHINGTON: JULY 1959

ABSTRACT

This report lists the biological data collected aboard research vessels Hugh M. Smith and John R. Manning and nine chartered commercial vessels during the Northeastern Pacific Albacore Survey (NEPAS). The survey was developed to map the distribution of albacore in the northern area of the United States west coast albacore fishery during the summer of 1957.

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Albacore tuna, Germo alalunga (Bonnaterre) were landed commercially in ports of Washington and Oregon for the first time in 1937. During 1939 they began to appear in exploratory catches of commercial vessels off British Columbia, Canada. By 1945 the annual commercial catch exceeded a million pounds. Large catches were consistently made off British Columbia by 1948 with good fishing extending as far north as Queen Charlotte Islands (Powell et al. 1952), which represented the farthest northward extension of the fishery. Following 1948 the fishery declined rapidly; by 1951 only a few albacore were taken commercially north of California.

The return of albacore to these northern waters was indicated in 1955 when scattered fish were reported from the area by research vessels of the University of Washington and of the United States Fish and Wildlife Service (Graham 1957, Holmberg 1955). In 1956, vessels from these agencies again reported fish in the area and commercial vessels, which followed up these reports, developed a small albacore fishery off Oregon (Anonymous 1956, Frolander and Lincoln 1956).

The Northeastern Pacific Albacore Survey or NEPAS was designed to map the distribution of albacore in this northern area and to determine how the distribution was related to oceanographic and biological phenomena. The survey was conducted by the Biological Laboratory of the Bureau of Commercial Fisheries at Honolulu, Hawaii, as a part of their Saltonstall-Kennedy (68 Stat. 376) albacore tuna project, and in cooperation with members of the fishing industry, and the fishery research agencies of California, Oregon, and Washington. The Pacific Marine Fisheries Commission acted as liaison for the cooperating agencies.

The survey area extended from 35°N. to 50°N. latitude and from 50 to 350 miles offshore. The southern limit of the survey area was just north of Point Arguello, California, which approximates the northern summer limit of the southern California albacore fishery. The northern limit approached generally the northernmost penetration of the west coast albacore fishery during the summer. Inshore and offshore limits were determined from data gathered on previous cruises which indicated that a definite scarcity of fish existed beyond these boundaries during the summer (Graham 1957, Anonymous 1957). Thus, the survey was placed off the coasts of northern California, Oregon, and Washington. The period covered was from July 22 to August 1 (1957), a time when the west coast albacore fishery could be expected to reach or approach its peak in production (Clemens 1955).

Nine charter vessels were assigned to the trolling tracks shown in figure 1. Six of the vessels carried scientific observers provided by California Fish and Game (2), Oregon Fish Commission (1), Washington State Department of Fisheries (1), and Honolulu Biological Laboratory (2). The vessels, operators, home ports, and names and agencies of the observers are given in table 1. The charter vessels were augmented by the two Honolulu Laboratory vessels, the Hugh M. Smith and the John R. Manning, which operated in the survey area making oceanographic and biological observations.

This report lists the biological data collected during the survey. They are presented here to make them readily available to other agencies studying the ecology of the albacore in the eastern Pacific. Descriptive and analytical publications will follow. Oceanographic and plankton data will also be the subjects of separate reports.

The John R. Manning departed on cruise 36 from Honolulu on June 14, 1957, to make a preliminary troll and gill-net survey of the area. The Manning travelled northeast to 42°N., 135°W. (see fig. 2), returned south to 31°N., and then zigzagged northward through the NEPAS area. The Manning arrived in Astoria, Oregon, on July 16 and remained there until the start of NEPAS on July 22. Subsequently, she proceeded

1/ Formerly the Pacific Oceanic Fishery Investigations.

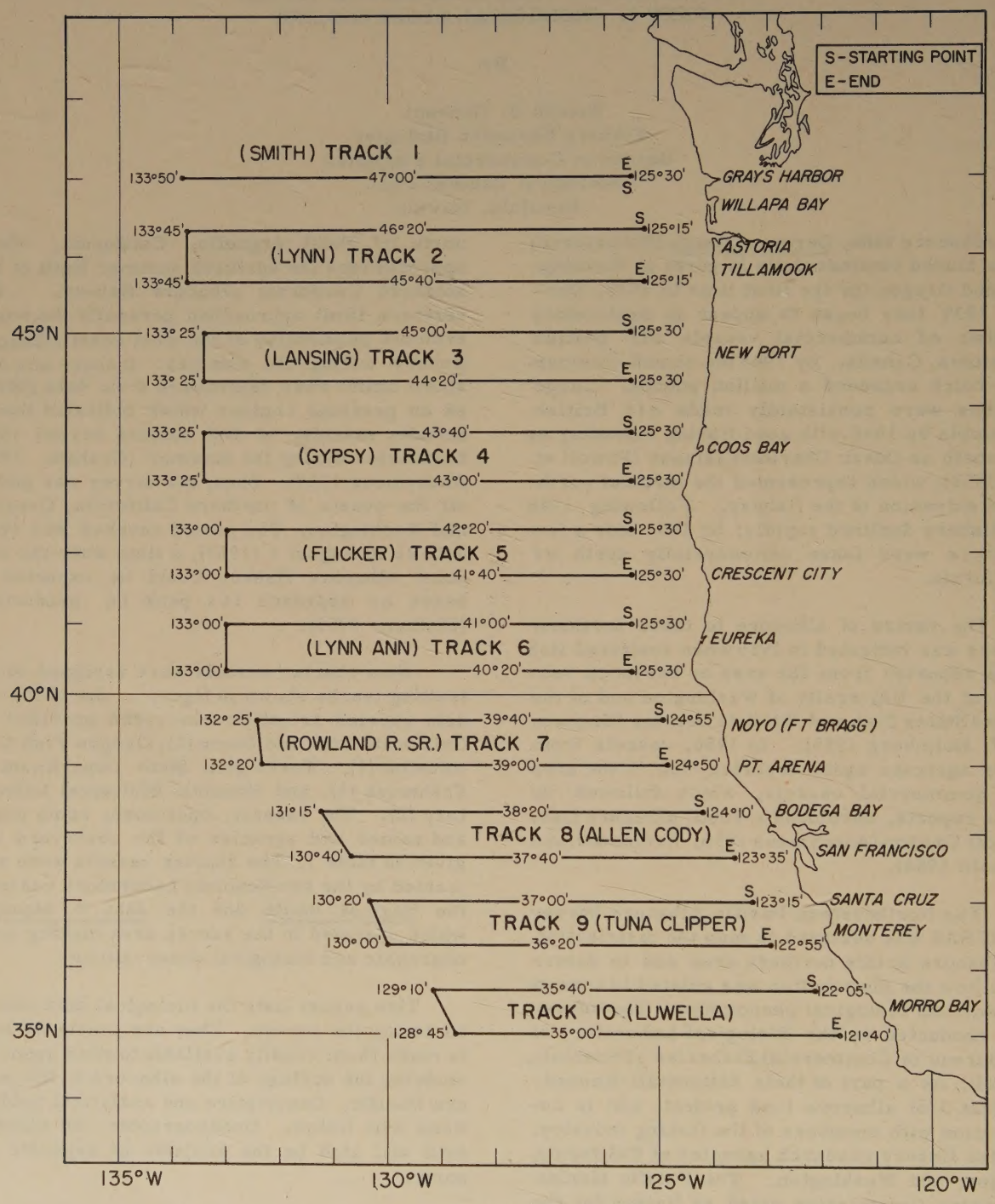

Figure 1.--Proposed trolling tracks for NEPAS and the names of the vessels assigned.

south through the NEPAS area, transferring equipment to the charter vessels, and then crossed into and out of the coastal band of cold water, and checked areas where the charter vessels reported good catches. The Manning returned to Honolulu August 20, 1957.

The Hugh M. Smith departed from Honolulu on cruise 40 on July 1, 1957, to run a line of oceanographic stations between Oahu and 38°35'N., 143°28'W. (see fig. 3). The Smith then conducted an oceanographic and trolling survey between 40°N. and 46°N. and arrived

Table 1.--NEPAS charter vessel data

Name	Owner[1/]	Home port	Scientific observer aboard	Organization
Allen Cody	Hunter and Foland (L. L. Newton, operator)	Fields Landing, California	Howard O. Yoshida	Honolulu Biological Laboratory
Flicker	Gus Wagner	Newport, Oregon	George Miller	Oregon Fish Commission
Gypsy	Jim Lyons	Seattle, Washington	William Stickley	Washington Department of Fisheries
Lancing	Oscar Knudsen	Seattle, Washington	None	-
Lynn	Les Withee (Josh Bufton, operator)	Garibaldi, Oregon	None	-
Lynn Ann	Herman Foland	Fields Landing, California	Thomas S. Hida	Honolulu Biological Laboratory
Luwella	O. James Bardeau	San Diego, California	Tom Jow	California Department of Fish and Game
Rowland R. Sr.	William R. Roland	El Cerrito, California	None	-
Tuna Clipper	Erling Kolnes (Floyd M. Rhoades, operator)	San Pedro, California	Robert L. Caldwell	California Department of Fish and Game

[1/] Except where operators are indicated, vessels were operated by the owners.

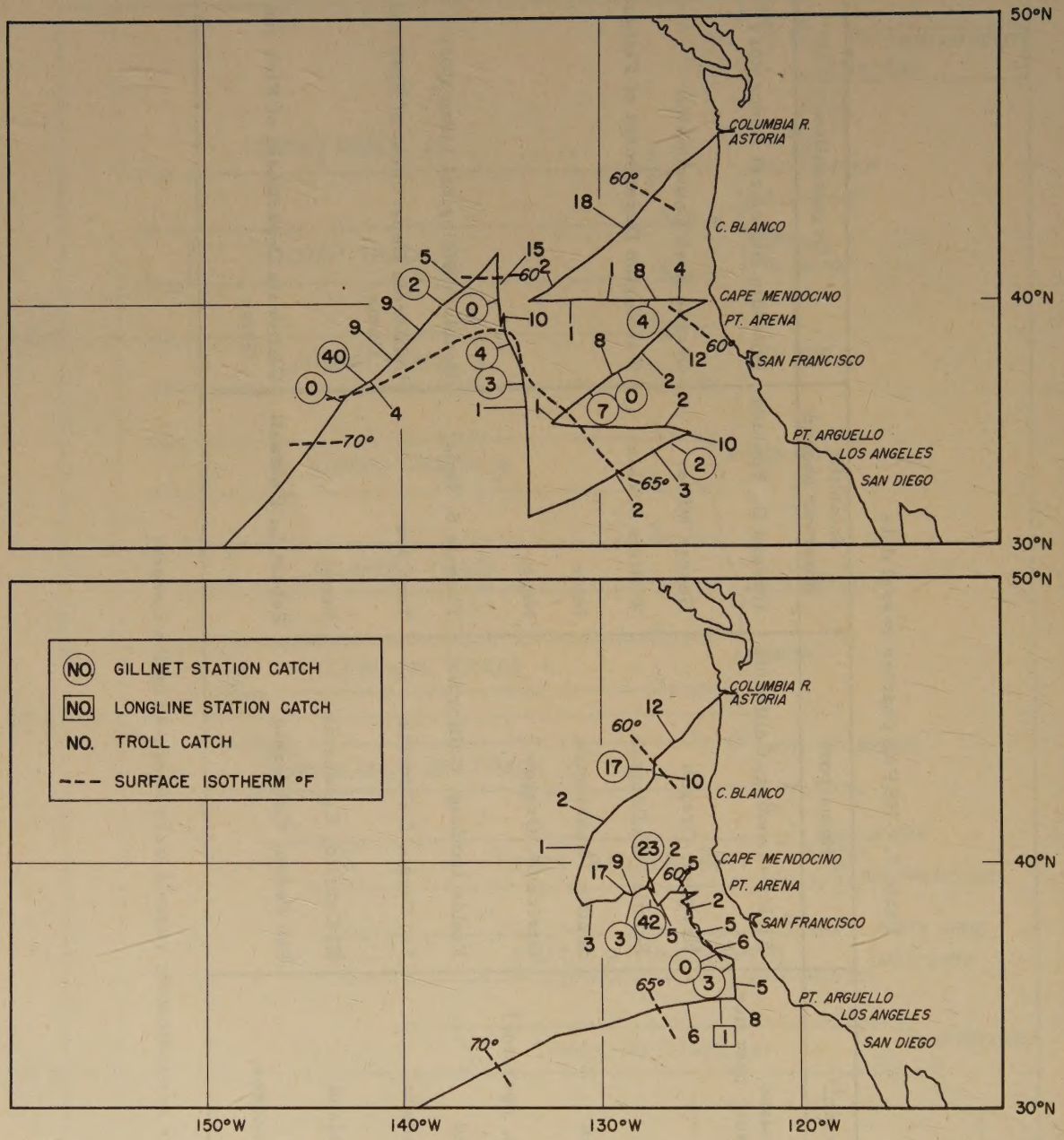

Figure 2.--Albacore tuna catches made with trolling gear, gill nets, and longline by the John R. Manning (cruise 36) during the Northeastern Pacific Albacore Survey. Upper panel shows catches on track outbound from Honolulu and lower panel shows catches on track outbound from Astoria, Oregon.

in Astoria, Oregon, on July 18. During the period July 22 to August 15, the Smith acted as coordinating vessel for the NEPAS survey, completed the northernmost trolling track of NEPAS, conducted an oceanographic and trolling survey of the NEPAS area, and adjusted her track to cover areas which had been assigned to vessels forced to withdraw from the survey. After a stop for repairs a Oakland, California, from August 15-26, 1957 the Smith completed the oceanographic and trolling survey of the NEPAS area and departed for Honolulu on August 29, agai occupying a line of oceanographic stations e route. She returned to Honolulu on September 5 1957.

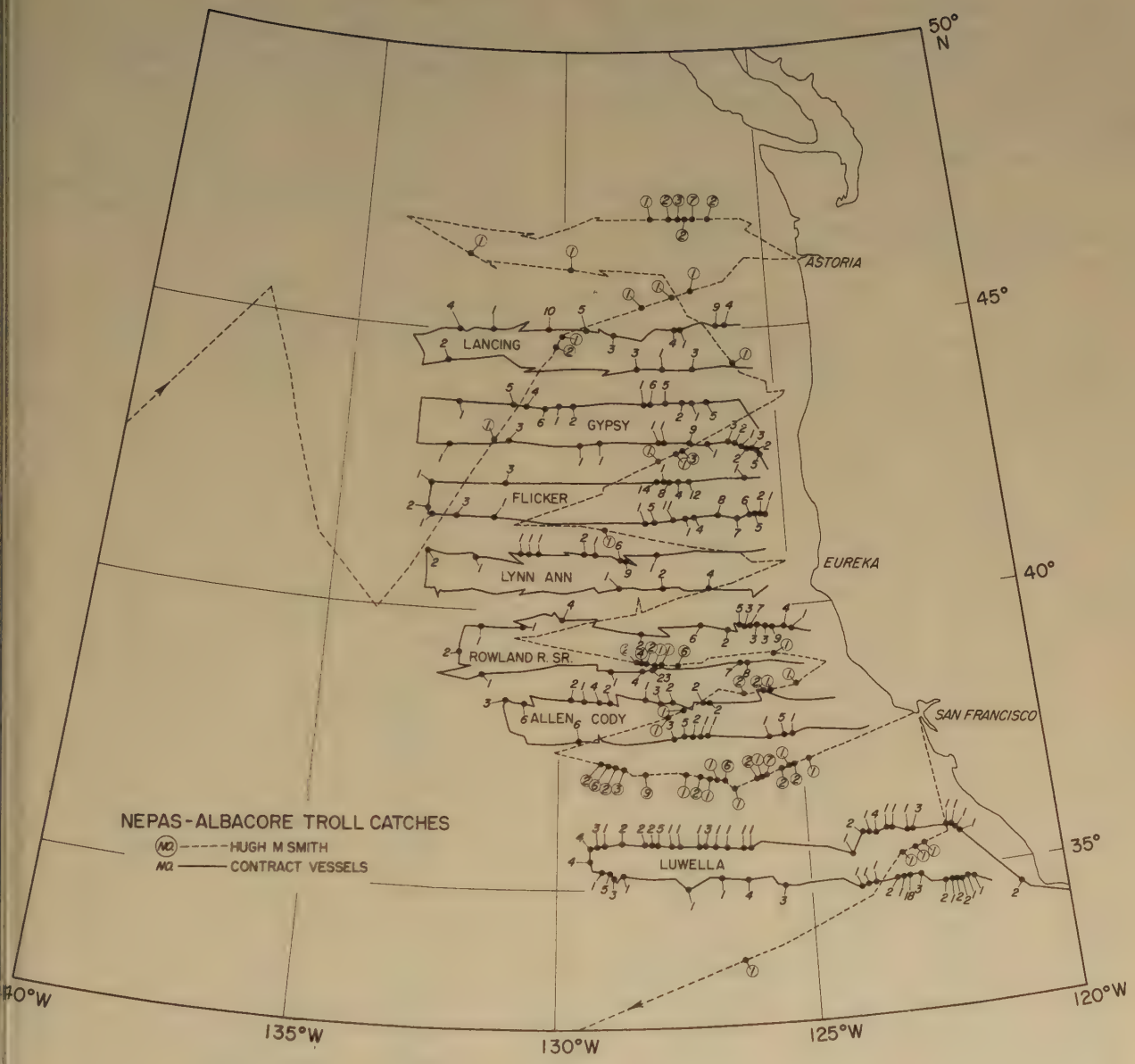

Figure 3.--Albacore tuna catches by the Hugh M. Smith and the charter vessels during the Northeastern Pacific Albacore Survey.

Eight of the charter vessels started the NEPAS survey on schedule on July 22, 1957; the ninth started on July 23. All vessels completed the survey of their assigned tracks on either July 31 or August 1 except the Tuna Clipper and the Lynn. The fresh-water supply of the Lynn became contaminated with salt water and she was forced to withdraw from the survey about 150 miles from her starting point. The Tuna Clipper encountered heavy weather at the start of the survey and was forced to return to port in a leaking condition after completing 30 miles of her track. Several of the other vessels sustained storm damage (e. g., the Luwella broke both trolling booms and her radio antenna), but they were able to make repairs en route and complete their tracks.

RESULTS OF FISHING

Trolling

Charter vessels trolled 6 to 12 lines at speeds generally varying from 5 to 7 knots. Daylight trolling along the tracks was continuous; the vessels drifted at night. The Smith

trolled 5 lines and the Manning 6 to 9 lines at speeds of 5 to 7 knots when in the survey area. A variety of jigs and feathered lures was used by all vessels. The troll catches of albacore are presented in tables 2, 3, and 4 and figures 2 and 3. Catch positions were not available for the charter vessel Lynn.

Albacore taken in viable condition on the troll lines were tagged and released. Charter vessels employed the California type G tag (Wilson 1953); Smith and Manning alternated the use of this tag with a new dart tag (Yamashita and Waldron 1958). The tagging results from each vessel are summarized in table 5. To date, 5 recoveries have been made (Otsu MS)[2/]

[2/] Otsu, T. MS. Albacore migration and growth in the North Pacific Ocean as estimated from tag recoveries. Biological Laboratory, Honolulu.

Table 2.--Albacore troll catch, Hugh M. Smith (cruise 40)

Date 1957	Zone time[1/]	Position		Number of fish	Fork length (cm.)			
		North latitude	West longitude					
7/15	1225	43°04'	131°34'	1	66.5			
7/16	1100	44°47'	130°04'	2	65.0,	75.0		
	1340	44°57'	130°01'	1	79.0			
7/17	0505	45°25'	128°08'	1	67.0			
	1110	45°38'	127°21'	1	68.0			
	1451	45°43'	126°51'	1	67.0			
7/22	1300	47°00'	126°18'	2	75.0,	80.0		
	1550	47°02'	126°35'	2	67.0,	68.0		
	1710	47°02'	126°40'	1	73.1			
	1740	47°02'	126°43'	2	65.4,	-		
	1805	47°02'	126°46'	2	62.2,	66.9		
	1915	47°02'	126°57'	2	65.3,	66.6		
	2045	47°02'	127°06'	1	77.8			
7/23	0505	47°00'	127°06'	2	71.1,	78.9		
	0602	47°00'	127°13'	1	79.3			
	0715	47°00'	127°18'	1	78.0			
	1140	47°01'	127°46'	1	64.9			
7/25	1630	46°22'	132°22'	1	64.8			
7/27	1455	46°05'	129°50'	1	76.5			
7/29	1308	44°20'	125°54'	1	67.3			
7/31	0600	42°48'	127°13'	3	53.8,	54.2,	82.1	
	0715	42°44'	127°23'	1	61.9			
	1110	42°36'	127°50'	1	64.8			
8/2	1545	41°23'	129°08'	1	71.4			
8/8	0525	39°03'	128°25'	2	76.5,	79.5		
	0725	39°01'	128°12'	4	67.1,	68.0,	68.0,	81.6
	0747	39°00'	128°09'	2	65.1,	68.0		
	0930	39°00'	127°58'	1	63.1			
	1005	38°50'	127°55'	1	63.2			
	1610	39°04'	127°31'	3	54.8,	54.8,	65.2	
	1640	39°04'	127°28'	3	52.4,	59.2,	69.7	
8/9	1447	39°09'	125°27'	1	57.5			
8/10	1107	38°37'	125°00'	1	69.2			
	1522	38°31'	125°30'	1	69.6			
	1620	38°30'	125°35'	2	74.5,	81.0		
	1915	38°26'	126°00'	1	66.3			
	1929	38°26'	126°02'	1	78.0			
8/11	0925	38°11'	127°24'	1	56.3			
	1335	38°02'	127°50'	1	65.5			

[1/] Consult the Standard Time Chart of the World (HO 5192) of the U. S. Hydrographic Office for zone boundaries.

Table 2.--Albacore troll catch, Hugh M. Smith (cruise 40) (cont'd)

Date 1957	Zone time 1/	Position		Number of fish	Fork length (cm.)				
		North latitude	West longitude						
/12	1450	37°16'	129°08'	2	60.4,	64.6			
	1515	37°16'	129°06'	4	65.6,	69.0,	- ,	-	
	1610	37°15'	129°01'	1	54.9				
	1626	37°15'	129°00'	1	55.5				
	1653	37°14'	128°57'	1	53.3				
	1745	37°11'	128°47'	1	53.4				
	1855	37°10'	128°43'	1	-				
	1930	37°10'	128°42'	2	67.3,	67.3			
/13	0640	37°02'	128°18'	4	67.2,	70.3,	70.3,	-	
	0700	37°02'	128°15'	5	69.8,	70.3,	78.6,	83.4,	83.4
	1340	37°01'	127°26'	1	65.3				
	1535	36°57'	127°11'	2	- ,	-			
	1655	36°56'	126°57'	1	65.2				
	1755	36°54'	126°51'	1	65.9				
	1920	36°52'	126°38'	1	66.2				
	1935	36°52'	126°36'	5	66.3,	66.8,	66.8,	- ,	-
/14	0555	36°48'	126°20'	1	57.4				
	0920	36°53'	125°58'	2	79.5,	81.1			
	0935	36°53'	125°57'	1	-				
	1000	36°57'	125°49'	1	67.1				
	1025	36°56'	125°45'	4	65.3,	65.3,	67.3,	70.8	
	1040	36°56'	125°44'	1	78.9				
	1052	36°57'	125°42'	1	77.4				
	1250	37°00'	125°27'	2	64.4,	70.0			
	1442	37°03'	125°10'	1	75.0				
	1600	37°05'	125°09'	2	64.4,	69.4			
	1808	37°08'	124°53'	1	67.7				
'27	0825	35°29'	122°40'	1	-				
	0945	35°25'	122°50'	1	78.9				
	1215	35°19'	123°07'	1	79.5				
'28	1150	33°39'	126°22'	1	85.4				

Table 3.--Albacore troll catch, John R. Manning (cruise 36)

ate 957	Zone time 1/	Position		Number of fish	Fork length (cm.)			
		North latitude	West longitude					
'19	1615	36°52'	142°44'	2	64.5,	66.3		
	1630	36°52'	142°44'	1	65.4			
	1635	36°52'	142°44'	1	65.6			
'20	1925	37°55'	140°20'	3	63.0,	66.1,	66.6	
	1930	37°55'	140°20'	4	64.6,	65.5,	67.4,	66.9
	1940	37°55'	140°20'	1	64.6			
	2005	37°55'	140°20'	1	63.9			
21	0655	38°44'	139°20'	1	64.5			
	0745	38°49'	139°15'	2	64.2,	66.8		
	0925	38°54'	139°08'	3	78.2,	78.3,	79.9	
	1110	39°01'	139°00'	2	63.7,	74.5		
	1922	39°40'	138°12'	1	68.5			

1/ Consult the Standard Time Chart of the World (HO 5192) of the U. S. Hydrographic Office for ne boundaries.

Table 3.--Albacore troll catch, John R. Manning (cruise 36)(cont'd)

Date 1957	Zone time[1/]	Position		Number of fish	Fork length (cm.)				
		North latitude	West longitude						
6/22	1510	40°23'	137°06'	1	65.7				
	1700	40°34'	136°52'	4	63.0,	66.9,	74.0,	74.2	
6/23	1130	41°33'	135°04'	2	75.8,	76.6			
	1410	41°11'	135°04'	4	75.0,	76.0,	76.2,	77.6	
	1700	40°55'	135°03'	3	66.4,	68.5,	-		
	1750	40°49'	135°03'	1	65.5				
	1820	40°47'	135°03'	1	79.0				
	1830	40°46'	135°03'	4	64.2,	65.5,	67.2,	74.8	
6/25	0830	39°47'	134°50'	4	61.7,	63.9,	66.7,	73.6	
	0905	39°46'	134°49'	4	54.3,	64.3,	65.0,	65.1	
	1930	38°32'	134°33'	2	63.9,	68.1			
6/27	1510	35°51'	133°47'	1	53.4				
6/30	1706	32°58'	129°30'	2	53.4,	53.9			
7/1	0855	33°52'	127°34'	2	63.2,	65.5			
	1315	34°09'	126°57'	1	77.3				
7/2	1120	34°38'	126°01'	1	75.5				
	1215	34°40'	125°54'	1	64.4				
	1615	34°49'	125°32'	2	61.8,	66.8			
	1620	34°49'	125°32'	2	64.6,	70.2			
	1645	34°50'	125°28'	2	63.6,	66.8			
	1750	34°52'	125°22'	2	65.9,	67.2			
7/3	0830	34°56'	126°58'	1	65.7				
	0920	34°56'	127°04'	1	75.3				
7/4	1730	35°05'	131°52'	1	67.3				
7/6	1615	37°11'	129°24'	8	61.5,	61.7,	62.9,	64.7,	65.0
					65.4,	66.3,	68.5		
7/7	1625	37°49'	128°28'	2	63.7,	64.2			
7/8	0610	38°45'	127°05'	1	64.5				
	0710	38°49'	127°00'	4	64.1,	64.3,	66.4,	67.9	
	0740	38°51'	126°58'	1	66.2				
	0745	38°51'	126°58'	3	63.7,	65.9,	68.5		
	1032	39°02'	126°43'	1	66.9				
	1100	39°02'	126°42'	2	65.3,	66.2			
7/9	1455	39°59'	126°34'	1	65.3				
	1705	39°59'	126°51'	3	65.5,	74.1,	77.8		
7/10	0920	40°02'	127°07'	3	63.4,	65.7,	65.8		
	1035	40°02'	127°16'	1	66.0				
	1130	40°02'	127°26'	1	78.9				
	1143	40°02'	127°26'	2	63.3,	64.3			
	1604	40°01'	127°54'	1	77.8				
7/11	0600	40°03'	129°38'	1	76.1				
	1906	40°09'	131°31'	1	77.1				
7/12	1400	40°11'	132°52'	1	63.9				
	1650	40°22'	132°33'	1	62.9				
7/14	0700	42°27'	128°57'	1	68.2				
	1225	42°51'	128°23'	1	61.7				
	1615	43°05'	128°07'	3	66.1,	67.7,	69.2		
	1745	43°13'	127°59'	3	66.0,	66.1,	67.1		
	1820	43°14'	127°57'	1	66.9				
	1840	43°16'	127°56'	1	64.2				
	1904	43°17'	127°55'	1	66.1				

[1/] Consult the Standard Time Chart of the World (HO 5192) of the U. S. Hydrographic Office for zone boundaries.

Table 3.--Albacore troll catch, John R. Manning (cruise 36) (cont'd)

Date 1957	Zone time[1/]	Position		Number of fish	Fork length (cm.)			
		North latitude	West longitude					
7/14	1920	43°18'	127°53'	1	63.8			
	2000	43°20'	127°51'	1	64.7			
	2022	43°20'	127°51'	1	64.0			
	2030	43°20'	127°51'	2	64.0,	64.9		
	2035	43°20'	127°51'	1	59.4			
	2040	43°20'	127°51'	1	66.9			
7/23	0635	44°32'	126°21'	2	79.6,	81.2		
	0753	44°26'	126°30'	1	67.7			
	0845	44°21'	126°38'	2	63.4,	66.2		
	1235	44°05'	127°02'	4	62.4,	75.9,	77.5,	79.2
	1450	43°54'	127°17'	1	61.6			
	1920	43°44'	127°46'	1	63.8			
	2000	43°42'	127°51'	1	67.9			
/24	0930	43°37'	127°40'	2	64.3,	65.7		
	1330	43°28'	127°09'	1	66.4			
	1505	43°16'	127°11'	1	65.7			
	1530	43°13'	127°12'	1	-			
	1730	43°07'	127°22'	2	60.4,	65.2		
	1930	43°00'	127°35'	1	69.2			
	2012	42°57'	127°40'	3	60.2,	64.2,	65.6	
/25	1545	41°36'	129°56'	1	68.2			
	1947	41°20'	130°17'	1	56.4			
/26	1945	39°52'	131°16'	1	60.9			
/27	1350	38°23'	130°25'	1	53.8			
	1400	38°24'	130°23'	1	55.2			
	1630	38°27'	130°11'	1	57.8			
/28	0610	38°46'	128°44'	1	54.0			
	0640	38°47'	128°40'	3	52.2,	55.4,	58.8	
	0705	38°48'	128°37'	2	54.0,	60.2		
	0745	38°48'	128°39'	1	55.3			
	0835	38°47'	128°39'	2	52.2,	58.8		
	1120	38°48'	128°28'	1	57.2			
	1445	38°49'	128°35'	3	56.9,	57.4,	58.3	
	1545	38°49'	128°40'	1	54.7			
	1600	38°49'	128°40'	1	55.5			
	1610	38°49'	128°44'	2	55.9,	57.0		
/29	0930	38°47'	128°31'	2	57.5,	-		
	1015	38°48'	128°29'	4	59.3,	73.3,	74.1,	84.3
	1800	39°00'	127°31'	3	53.3,	54.8,	55.4	
/2	1030	39°27'	127°30'	2	54.1,	55.3		
/3	0830	38°57'	127°18'	1	63.7			
	1045	38°55'	127°05'	4	74.7,	74.8,	75.1,	83.9
/4	1135	38°55'	125°36'	2	65.0,	66.3		
	1630	38°58'	126°17'	2	65.5,	76.1		
	1730	38°58'	126°26'	1	62.6			
/5	0700	38°22'	125°53'	1	68.8			
	0850	38°17'	125°44'	1	74.9			
/6	0603	37°25'	125°12'	1	65.8			
	0615	37°25'	125°12'	1	67.6			
	0800	37°14'	125°12'	1	60.6			
	1112	37°00'	125°01'	2	62.0,	62.0		
/7	0725	36°41'	124°29'	1	66.2			

[1/] Consult the Standard Time Chart of the World (HO 5192) of the U. S. Hydrographic Office for one boundaries.

Table 3.--Albacore troll catch, John R. Manning (cruise 36) (cont'd)

Date 1957	Zone time[1/]	Position		Number of fish	Fork length (cm.)
		North latitude	West longitude		
8/7	0940	36°35'	124°17'	3	60.7, 66.3, 69.2
	1200	36°29'	124°07'	1	68.1
	1706	36°08'	123°29'	1	59.8
8/8	1645	35°11'	123°23'	3	74.6, 74.9, 80.1
	1900	34°55'	123°22'	2	63.7, 68.0
8/9	0900	34°05'	123°39'	1	64.5
	1030	34°47'	123°45'	1	63.0
	1315	34°50'	124°08'	2	54.2, 57.8
	1320	34°50'	124°10'	1	67.3
	1915	34°46'	124°14'	3	63.8, 66.6, 67.7
8/10	0610	34°19'	125°40'	1	55.8
	0720	34°18'	125°52'	2	52.3, 53.5
	1025	34°17'	126°10'	2	53.1, 54.3
	1800	34°09'	127°08'	1	81.5

[1/] Consult the Standard Time Chart of the World (HO 5192) of the U. S. Hydrographic Office for zone boundaries.

Table 4.--Albacore troll catch, charter vessels

Date 1957	Zone time[1/]	Position		Number of fish	Fish length (cm.)
		North latitude	West longitude		
Lancing					(Estimated average)
7/22	0900	45°01'	126°12'	4	76
	1130	45°03'	126°22'	9	68
	1715	45°04'	127°11'	1	68
7/23	0430	45°00'	127°19'	4	66
	1600	44°50'	128°54'	1	66
	1645	44°50'	128°54'	2	66
7/24	0930	45°00'	129°40'	5	69
	1820	45°02'	130°20'	2	69
	1840	45°02'	130°20'	8	69
7/25	1430	45°00'	131°45'	1	69
7/26	0845	44°59'	132°30'	3	69
	0930	45°00'	132°30'	1	69
7/27	1530	44°27'	132°50'	2	69
7/30	1120	44°19'	128°20'	3	69
	1845	44°20'	127°20'	1	69
7/31	0800	44°20'	126°55'	3	69
Gypsy					(Estimated average)
7/22	1845	43°40'	126°37'	5	64
	2040	43°42'	126°57'	1	69
7/23	0655	43°40'	127°09'	2	64
	0950	43°42'	127°33'	5	62
	1405	43°42'	127°55'	3	65

[1/] Consult the Standard Time Chart of the World (HO 5192) of the U. S. Hydrographic Office for zone boundaries.

Table 4.--Albacore troll catch, charter vessels (cont'd)

Date 1957	Zone time[1/]	Position		Number of fish	Fish length (cm.)
		North latitude	West longitude		
Gypsy - (cont'd)					(Estimated average)
7/23	2000	43°42'	127°54'	3	63
7/24	0445	43°40'	128°03'	1	64
7/25	0500	43°38'	128°52'	2	64
	0700	43°00'	130°05'	1	64
	0950	43°35'	130°26'	6	59
	1445	43°40'	130°54'	4	66
	1725	43°42'	131°08'	5	81
7/26	1510	43°41'	132°29'	1	61
7/28	0920	42°57'	132°33'	1	76
	1915	43°02'	131°15'	1	66
	1930	43°02'	131°15'	2	69
7/29	1825	42°57'	129°35'	1	53
7/30	0830	43°00'	129°10'	1	53
	1930	43°00'	127°48'	1	53
7/31	0530	42°59'	127°43'	1	64
	1105	42°57'	126°59'	3	66
	1210	42°57'	126°59'	1	58
	1225	42°57'	126°58'	1	66
	1235	42°57'	126°57'	4	69
	1420	42°55'	126°39'	1	66
	1830	42°59'	126°10'	3	69
	2005	42°57'	126°05'	2	66
8/1	0705	42°49'	125°50'	1	66
	0825	42°50'	125°47'	2	81
	0900	42°50'	125°11'	1	69
	0920	42°50'	125°38'	1	79
	0940	42°50'	125°37'	1	81
	0950	42°50'	125°36'	2	76
	1005	42°50'	125°34'	5	74
Flicker					(Fork length, cm.)
7/22	0800	42°20'	125°42'	1	63
7/23	0545	42°20'	127°03'	9	64, 64, 64, 64, 65, 65, 65, 66, 68
	0610	42°20'	127°03'	3	63, 64, 65
	0900	42°20'	127°25'	4	63, 63, 65, 67
	0945	42°20'	127°33'	8	61, 64, 64, 65, 65, 66, 78, 78
	1030	42°20'	127°36'	1	71
	1235	42°20'	127°50'	8	64, 65, 66, 66, 66, 67, 74, 79
	1300	42°20'	127°51'	6	65, 65, 65, 66, 68, 69
/25	1515	42°22'	131°17'	3	54, 54, 54
7/26	1700	42°15'	133°00'	1	76
/27	0800	41°44'	133°00'	2	54, 55
	1000	41°40'	132°53'	1	56
	1400	41°40'	132°25'	3	54, 54, 54

[1/] Consult the Standard Time Chart of the World (HO 5192) of the U. S. Hydrographic Office for zone boundaries.

Table 4.--Albacore troll catch, charter vessels (cont'd)

Date 1957	Zone time[1/]	Position		Number of fish	Fish length (cm.)
		North latitude	West longitude		
Flicker - (cont'd)					(Fork length, cm.)
7/28	0630	41°39'	131°30'	1	64
7/30	0845	41°34'	128°03'	1	64
	1000	41°35'	127°56'	5	54, 54, 54, 54, 66
	1430	41°37'	127°30'	11	55, 55, 55, 59, 60, 61, 61, 62, 65, 66, 67
	1730	41°39'	127°15'	1	57
	1945	41°40'	127°04'	1	66
	2000	41°40'	127°04'	3	55, 56, 57
7/31	0845	41°40'	126°35'	5	64, 65, 65, 66, 68
	0910	41°40'	126°33'	3	52, 64, 65
	1400	41°40'	126°07'	3	63, 64, 66
	1430	41°40'	126°04'	4	64, 65, 66, 66
	1645	41°40'	125°51'	6	63, 64, 64, 65, 65, 65
	1750	41°40'	125°46'	5	64, 66, 67, 69, 75
	1900	41°40'	125°40'	2	64, 66
	2030	41°40'	125°30'	1	65
Lynn Ann					(Estimated average)
7/23	1245	41°00'	127°57'	1	65
7/24	0825	40°55'	128°37'	6	61
	0900	40°55'	128°37'	2	61
	0940	40°56'	128°40'	1	61
	1115	40°59'	128°47'	6	57
	1550	41°00'	129°23'	1	-
	1715	41°01'	129°30'	2	-
7/25	1320	41°00'	130°33'	1	65
	1715	41°01'	130°46'	1	58
	1855	41°01'	130°54'	1	80
7/26	1530	40°57'	131°56'	1	58
7/27	1155	41°00'	133°00'	2	55
7/30	1007	40°24'	128°42'	1	78
	1715	40°24'	127°45'	2	64
7/31	1147	40°22'	126°43'	4	66
Rowland R. Sr.					(Fork length, estimated)
7/22	0805	39°34'	125°00'	1	67
	0930	39°35'	125°10'	4	67, 70, 70, 73
	1200	39°37'	125°35'	9	65, 67, 67, 67, 67, 69, 69, 69, 70
	1310	39°40'	125°40'	3	69, 70, 70
	1422	39°41'	125°47'	1	69
	1450	39°41'	125°49'	2	61, 65
	1620	39°42'	125°59'	6	61, 63, 66, 66, 68, 69
	1645	39°42'	125°00'	1	69
	1720	39°42'	126°04'	3	67, 67, 69
	1820	39°42'	126°08'	5	65, 67, 69, 70, -

[1/] Consult the Standard Time Chart of the World (HO 5192) of the U. S. Hydrographic Office for zone boundaries.

Table 4. --Albacore troll catch, charter vessels (cont'd)

Date 1957	Zone time[1/]	Position		Number of fish	Fish length (cm.)
		North latitude	West longitude		
Rowland R. Sr.					(Fork length, estimated)
7/23	0542	39°40'	126°25'	2	69, 70
	1145	39°44'	127°00'	6	61, 66, 69, 69, 69, 70
7/24	1100	39°34'	128°14'	2	69, 69
7/25	1107	39°48'	130°00'	4	56, 56, 57, 57
7/26	0600	39°44'	130°45'	1	55
	1508	39°45'	131°44'	1	53
7/27	1405	39°15'	132°13'	2	56, 57
7/28	1355	38°50'	131°41'	1	57
7/30	0845	38°56'	128°56'	1	57
	1425	38°55'	128°15'	2	53, 57
	1455	38°56'	128°12'	2	59, 63
	1630	38°58'	128°00'	23	53, 53, 53, 53, 53, 55, 55, 56, 56, 56, 56, 56, 56, 56, 56, 56, 56, 57, 57, 57, 57, -
7/31	0750	39°05'	126°16'	3	61, 61, 62
8/1	0530	39°04'	126°18'	1	66
	0645	39°04'	126°17'	3	65, 66, 69
	0715	39°03'	126°08'	4	67, 67, 69, -
	0730	39°03'	126°06'	1	69
	0740	39°02'	126°06'	3	66, 67, 69
Allen Cody					(Fork length)
7/24	1430	38°18'	126°52'	2	55.6, 55.6
	1635	38°18'	127°08'	2	57.3, 58.7
7/25	1100	38°21'	127°42'	2	56.3, 59.4
	1230	38°23'	127°53'	3	61.5, 66.0, 78.6
	1540	38°25'	128°10'	1	61.0
7/26	0710	38°21'	128°52'	2	56.0, 57.6
	0835	38°25'	129°03'	4	53.8, 54.5, 54.9, 55.4
	1020	38°25'	129°18'	1	75.7
	1425	38°25'	129°47'	2	53.9, 54.9
7/27	0900	38°23'	130°44'	6	53.0, 53.0, 53.9, 54.4, 55.0, 55.5
	1135	38°24'	131°11'	3	53.0, 53.3, 54.0
7/28	1340	37°37'	129°42'	6	53.9, 57.0, 57.0, 67.4, 82.7, 86.7
7/30	0830	37°42'	127°37'	3	58.7, 59.5, 62.5
	0920	37°42'	127°29'	4	56.0, 57.0, 58.4, 59.0
	0935	37°42'	127°27'	1	56.0
	1035	37°41'	127°20'	2	66.0, 67.0
	1245	37°40'	127°03'	1	57.9
	1320	37°40'	126°55'	1	65.7
7/31	1125	37°39'	125°39'	1	72.4
	1415	37°40'	125°22'	5	4 fish estimated - 65 cm., 67.5
	1535	37°42'	125°10'	1	68.4

[1/] Consult the Standard Time Chart of the World (HO 5192) of the U. S. Hydrographic Office for zone boundaries.

Table 4.--Albacore troll catch, charter vessels (cont'd)

Date 1957	Zone time[1/]	Position		Number of fish	Fish length (cm.)
		North latitude	West longitude		
Tuna Clipper					(Fork length)
7/22	1017	37°00'	123°18'	1	78.5
Luwella					(Fork length)
7/22	0630	35°39'	122°04'	1	68.0
	0740	35°41'	122°10'	1	73.0
	0810	35°45'	122°12'	1	67.5
	1300	35°44'	122°45'	1	64.5
	1610	35°43'	122°58'	3	55.5, 59.2, 64.9
	1700	35°41'	123°04'	1	68.5
7/23	0600	35°48'	123°22'	1	75.8
	0630	35°48'	123°27'	1	53.7
	1000	35°45'	123°37'	4	54.1, 65.9, 66.5, 79.5
	1100	35°48'	123°46'	1	52.4
	1200	35°42'	123°54'	1	61.5
	1230	35°41'	123°55'	1	63.5
	1630	35°27'	124°20'	1	66.4
7/25	1145	35°35'	126°22'	1	76.0
	1300	35°36'	126°30'	1	75.5
	1655	35°42'	126°42'	1	62.3
7/26	0640	35°42'	126°58'	1	59.5
	0720	35°43'	127°03'	1	57.5
	0745	35°43'	127°05'	2	52.9, 54.5
	0810	35°45'	127°12'	1	53.5
	1130	35°45'	127°35'	1	65.5
	1220	35°45'	127°41'	1	65.5
	1340	35°44'	128°02'	5	64.0, 64.5, 64.5, 64.5, 65.5
	1430	35°44'	128°06'	2	55.0, 67.0
	1533	35°45'	128°15'	2	65.5, 67.1
7/27	0645	35°44'	128°41'	2	64.0, 68.1
	1000	35°44'	129°10'	1	53.3
	1035	35°44'	129°14'	1	68.0
	1100	35°44'	129°17'	2	64.1, 67.4
	1145	35°45'	129°23'	1	59.1
	1235	35°44'	129°22'	3	53.5, 64.0, 66.5
	1400	35°30'	129°20'	1	60.6
	1425	35°28'	129°28'	3	60.5, 65.3, 66.5
	1609	35°21'	129°12'	1	65.0
	1700	35°18'	129°07'	1	68.0
	1715	35°18'	129°06'	4	64.5, 65.0, 65.5, 66.5
	1925	35°10'	128°50'	3	51.2, 63.8, 66.5
7/28	0800	35°11'	128°44'	1	53.2
7/29	0620	35°04'	127°24'	2	69.4, 70.0
	1155	35°07'	126°47'	1	66.6
	1640	35°07'	126°11'	4	64.5, 65.5, 67.5, 67.7
	1914	35°08'	126°00'	2	65.9, 66.1
7/30	0730	34°57'	125°30'	3	64.5, 75.0, 75.5
/31	0545	34°48'	124°00'	1	63.5

[1/] Consult the Standard Time Chart of the World (HO 5192) of the U. S. Hydrographic Office for zone boundaries.

Table 4.--Albacore troll catch, charter vessels (cont'd)

Date 1957	Zone time 1/	Position		Number of fish	Fish length (cm.)
		North latitude	West longitude		
Luwella - (cont'd)					(Fork length)
7/31	0740	34°49'	124°05'	1	66.5
	0940	34°54'	123°50'	1	77.0
	1523	34°55'	123°20'	2	65.5, 67.5
	1615	34°56'	123°13'	1	72.4
	1640	34°56'	123°09'	18	59.0, 62.5, 63.5, 63.5, 64.0, 64.5, 65.0, 65.5, 65.5, 65.5, 66.0, 66.5, 66.5, 67.0, 67.4, 68.3, 71.3, 75.5
	1910	34°56'	122°50'	3	64.5, 66.5, 67.5
8/1	0743	34°48'	122°24'	2	64.5, 66.3
	0805	34°49'	122°21'	1	68.5
	0830	34°49'	122°16'	1	64.5
	0900	34°49'	122°13'	1	66.5
	1000	34°49'	122°06'	2	66.0, 68.3
	1100	34°49'	122°00'	1	68.5
	1130	34°49'	121°57'	1	66.5

1/ Consult the Standard Time Chart of the World (HO 5192) of the U. S. Hydrographic Office for zone boundaries.

Table 5.--Troll catch and number of albacore tuna tagged by Honolulu Biological Laboratory and charter vessels

Track number	Vessel	Total catch	Total tagged
-	Hugh M. Smith	112	71
-	John R. Manning	226	104
2	Lynn	23	10
3	Lancing	50	0
4	Gypsy	75	61
5	Flicker	102	100
6	Lynn Ann	32	21
7	Rowland R. Sr.	97	0
8	Allen Cody	53	29
9	Tuna Clipper	1	0
10	Luwella	108	72
Total		879	468

Gill-net Fishing

Eighteen shackles of gill nets with meshes varying from 4 1/2 to 7 1/2 inches, stretched measure, were fished by the Manning. An individual set consisted of a 7 1/2-inch mesh shackle placed at each end of the set and adjoining one of these was a 4 1/2-inch mesh shackle; and eight 5 1/2-inch mesh and seven 6 1/2-inch mesh shackles were alternated in the center of the set. Construction details of the nets are given by Graham and Mann (MS)3/.

Sets were usually made at dusk and retrieved at dawn. One 24-hour station was completed in an area of abundance off Point Arena immediately following an overnight set in which 42 albacore were captured (fig. 2). The 18-shackle set was halved for this operation and five baskets of longline, described below, were attached to an end of each half. Four 6-hour consecutive sets were made, alternating the two halves, between the hours of 1500 on July 30 and 1531 on July 31.

Gill-net catches made during the cruise are given in tables 6 and 7; the lengths of the albacore caught are listed in table 8. A list of the common names of fishes appearing in these tables and other portions of this report is presented in table 9 along with the corresponding scientific names.

3/ Graham, J. J. and H. J. Mann. MS. Construction and catch selectivity of albacore gill nets in the central North Pacific. Biological Laboratory, Honolulu.

Table 6.--Gill net and attached longline catch, John R. Manning (cruise 36)

Station	Date 1957	Set position		Albacore	Great blue shark	Pomfret	Squid	Miscellaneous	Total	Longline
		North latitude	West longitude							
9	6/18	36°09'	142°52'	0	0	5	2	1 dolphin	8	1 bigeye tuna
11	6/19	36°53'	141°41'	40	1	7	2	1 dolphin	51	
14	6/21	39°42'	138°11'	2	1	3	0	0	6	3 great blue shark
20	6/24	39°57'	134°56'	0	0	6	0	1 scad	7	1 great blue shark
23	6/25	38°32'	134°33'	4	0	3	0	0	7	
24	6/26	36°52'	133°51'	3	1	2	2	0	8	
34	7/1	34°25'	126°24'	2	0	17	0	4 scad	23	3 great blue shark
43	7/5	36°37'	130°12'	7	0	17	1	1 scad 1 dolphin	27	1 great blue shark
46	7/6	37°19'	129°10'	0	1	34	2	7 scad	44	2 great blue shark
50	7/9	39°59'	126°51'	4	37	7	0	5 scad	53	9 great blue shark
66	7/23	43°42'	127°53'	17	23	42	3	1 scad	86	2 great blue shark
81	7/28	38°45'	128°37'	3	10	14	0	0	27	1 great blue shark
83	7/29	39°00'	127°31'	42	45	44	3	14 scad 2 unidentified tuna 1 bonito shark	151	1 great blue shark
83[1/]	7/30	39°01'	127°26'	23	42	34	3	0	102	9 great blue shark
99	8/6	36°45'	124°34'	0	24	10	0	8 scad 1 Risso porpoise	43	9 great blue shark
102	8/9	34°50'	124°10'	3	21	30	1	30 scad 8 unknown	93	10 great blue shark
Total				149[2/]	206	275	19	71 scad 8 unknown 3 dolphin 2 unidentified tuna 1 bonito shark 1 Risso porpoise	736	51 great blue shark 1 bigeye tuna

[1/] 24-hour station.

[2/] An additional unidentified tuna was taken in the gill net and mistaken for albacore. Thus its station could not be determined and the albacore total is given as 149 rather than the 150 to which the column totals.

Table 7.--Twenty-four hour gill-net station 83, 38°58'N., 127°28'W., 7/30-7/31, John R. Manning (cruise 36)

Zone time[1]	Albacore		Great blue shark		Pomfrets		Squid		Attached longline catch-great blue shark		Totals
	alive	dead	alive	dead	alive	dead	alive	dead	alive	dead	
1502-2153	0	6	1	3	7	3	1	0	1	0	22
2003-0358	0	17	12	9	3	16	1	0	1	1	63[2]
0230-0942	0	0	11	3	0	5	0	0	0	0	20[3]
0828-1531	0	0	2	0	0	0	0	0	3	1	6
Total	0	23	26	15	10	24	2	0	5	2	

[1] Consult the Standard Time Chart of the World (HO 5192) of the U. S. Hydrographic Office for zone boundaries.

[2] One squid and 1 great blue shark not recorded as to viableness.

[3] One great blue shark not recorded as to viableness.

Table 8.--Length frequency of albacore captured in gill nets

Fork length (cm.)	Station												Total
	11	14	23	24	34	43	50	66	81	83	24-hour station	102	
50	-	-	-	-	-	-	-	-	-	2	-	-	2
51	-	-	-	-	-	-	-	-	-	10	2	-	12
52	-	-	-	-	-	-	-	-	-	6	4	-	10
53	-	-	-	-	-	-	-	-	-	4	2	-	6
54	-	-	1	-	-	-	-	-	1	8	1	-	11
55	-	-	-	-	-	-	-	-	-	2	5	-	7
56	1	-	-	-	-	-	-	-	2	3	2	-	8
57	-	-	-	-	-	-	-	-	-	2	1	-	3
58	-	-	-	-	-	-	-	-	-	-	-	-	-
59	1	-	-	-	-	-	-	-	-	-	-	-	1
60	4	-	-	-	-	-	-	-	-	-	-	-	4
61	2	-	-	-	-	-	1	-	-	1	-	-	4
62	6	-	-	-	-	-	-	1	-	-	1	-	8
63	4	-	-	-	-	2	-	1	-	-	1	1	9
64	5	1	-	1	-	3	1	3	-	2	-	-	16
65	6	-	-	1	1	1	-	6	-	-	-	1	16
66	6	-	3	-	-	1	-	2	-	-	1	-	13
67	2	-	-	-	1	-	2	1	-	-	1	-	7
68	-	-	-	1	-	-	-	1	-	-	-	1	3
69	-	-	-	-	-	-	-	-	-	1	-	-	1
70	-	-	-	-	-	-	-	-	-	-	-	-	-
71	-	-	-	-	-	-	-	-	-	-	-	-	-
72	-	-	-	-	-	-	-	-	-	-	-	-	-
73	-	-	-	-	-	-	-	-	-	-	1	-	1
74	-	1	-	-	-	-	-	1	-	-	-	-	2
75	-	-	-	-	-	-	-	-	-	-	-	-	-
76	-	-	-	-	-	-	-	1	-	-	-	-	1
77	-	-	-	-	-	-	-	-	-	1	-	-	1
78	-	-	-	-	-	-	-	-	-	-	-	-	-
79	-	-	-	-	-	-	-	-	-	-	-	-	-
80	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 9.--Common and scientific names of fishes mentioned in this report

Common name	Scientific name
Albacore tuna	Germo alalunga (Bonnaterre)
Bigeye tuna	Parathunnus sibi (Temminck and Schlegel)
Bonito shark	Isurus glaucus (Müller and Henle)
Dolphin	Coryphaena hippurus (Linnaeus)
Flying fish	Exocoetidae
Great blue shark	Prionace glauca (Linnaeus)
Lantern fish	Myctophidae
Pomfret	Brama raii (Block)
Saury	Cololabis saira (Brevoort)
Scad	Trachurus symmetricus (Ayres)
Skipjack tuna	Katsuwonus pelamis (Linnaeus)
Sunfish	Mola mola (Linnaeus)

Longline Fishing

Five baskets of longline were fished with each set of gill nets by attaching them to an end of the set. The longline was similar to that used previously to fish albacore in this area (Mann 1955). The basic unit or basket consisted of 210 fathoms of mainline to which floats were attached at either end. Three-fathom droppers with 1 1/2-fathom leaders were suspended from the mainline at 15-fathom intervals so that there were 13 hooks to a basket. This basic gear was modified to fish at varying depths by changing the depth of the floatline and placing an extra buoy at the center of the basket (omitting the hook at that position). The five baskets were arranged in the following order, starting at the attached end: Two had 3 buoys (one in the center) and no floatlines; two had 2 buoys and no floatlines; and the fifth had 2 buoys and 2-fathom floatlines. A sounding tube (Graham 1957) was placed on each basket of gear; and these showed that during the cruise the minimum fishing depth was about 25 feet and the maximum about 430 feet. No albacore were taken on this gear (tables 6 and 7).

A single albacore (68.6 cm. in fork length) was captured on a special set of longline which replaced a scheduled gill-net station cancelled because of a winch breakdown. Five baskets, each equipped with 3 buoys (one in the center) and no floatlines, were fished. This special set was made immediately following a catch of fish on trolling lines and extended from 1345 through 1800 hours (fig. 2). The hooks were baited with small herring (< 6 inches), in contrast to the five baskets attached to gill nets on which large herring (> 6 inches) were used.

STOMACH ANALYSES

One hundred and ninety-five albacore stomachs were examined in the field and 43 stomachs, believed to contain food, were preserved for laboratory analysis. In the field study, food items were divided into the following major groups: Squid, saury, other fish, shrimp-like plankton, and copepod and amphipod-like plankton. Food items of the first three groups were rated as to size by considering total lengths less than 5 inches as small, 5 through 10 inches as medium, and greater than 10 inches as large. The displacement volume (> 5 ml.) of the contents of each stomach was determined and any unidentifiable remains noted. The data obtained with both types of gear, troll and gill net, are presented in table 10.

HOLDING EXPERIMENTS

The rectangular port brine tank, 8 1/2 feet deep and 6 1/2 feet wide fore and aft, of the John R. Manning was used to hold troll-caught albacore which were landed alive and in good condition. Water entering the tank flowed diagonally across the upper portion of the tank and then returned along its sides and bottom. Water was removed from the bottom diagonally across from the inflow. The volume of flow was such that the contents of the 2,150-gallon tank were replaced approximately every 35 minutes. Fourteen albacore, ranging from 54 cm. to 68 cm. in fork length, were held in the tank for periods varying from a few minutes to 14 hours (table 11).

NIGHT-LIGHT OBSERVATIONS

Observations of organisms under lights were made from the Smith (table 12), the Manning (table 13), and two charter vessels (table 14) while they were drifting at night. The Smith made her observations under deck lights, which remained on all night, by estimating every 2 hours the number and size of sauries present. The Manning turned on the deck lights for 1 hour during darkness and estimated the number, and usually the size, of sauries and squids which were attracted. The charter vessel Flicker made observations between 2130 and 2200 hours each night using a single sealed-beam light. Twenty or fewer sauries, when seen at one instant during the period of observation, were classed as few, 21 to 50 as moderate, and 51 or more as abundant. The Rowland R. Sr. made her observations at 2200 and the amount of bait or forage and the amount of luminescence were recorded in relative terms.

SIGHTINGS OF FISH, BIRDS, AQUATIC MAMMALS

The wheel watches of the Smith and Manning maintained logs of fish, birds, and aquatic mammals sighted during the daylight hours. These observations are tabulated in tables 15 and 16. The charter vessels also maintained a rough log of such sightings which are tabulated in table 17.

Table 10.--Field examination of albacore stomach contents, John R. Manning (cruise 36)
Gill net-caught fish, (S = < 5 inches, M = 5-10 inches, L = > 10 inches)

Date 1957	Station	Squid			Saury			Other fish			Plankton		Unidentifiable remains	Volume ml.
		S	M	L	S	M	L	S	M	L	Shrimp-like	Copepod and amphipod-like		
6/20	11	-	-	-	-	2	-	-	-	-	-	-	x	40
6/20	11	2	-	-	-	-	-	3	-	-	1	-	x	10
6/20	11	-	-	-	-	-	-	1	1	-	1	-	x	25
6/20	11	1	-	-	-	-	-	1	-	-	3	-	x	10
6/20	11	-	-	-	-	-	3	-	-	-	-	-	-	110
6/20	11	-	-	-	-	2	-	-	-	-	-	-	-	60
6/20	11	3	1	-	-	-	-	-	-	-	7	-	-	10
6/20	11	-	1	-	-	-	-	-	-	-	1	-	x	7
6/20	11	3	-	-	1	-	-	7	-	-	-	-	x	20
6/20	11	26 albacore examined, all < 5 ml.												< 5
6/22	14	2 albacore examined, both < 5 ml.												< 5
6/26	23	4 albacore completely empty												< 5
7/2	34	-	1	-	-	-	-	-	1	-	-	-	x	8
7/2	34	-	-	-	-	-	-	-	-	-	-	-	x	< 5
7/6	43	-	-	-	-	-	-	-	-	-	-	-	-	< 5
7/6	43	2	-	-	-	-	-	-	1	-	-	-	x	13
7/6	43	6	2	-	-	1	-	1	-	-	-	-	x	20
7/6	43	-	-	1	-	-	-	-	-	-	-	-	x	9
7/6	43	-	-	-	-	-	-	-	-	-	-	-	-	< 5
7/6	43	-	-	-	-	-	-	-	-	-	-	-	-	< 5
7/10	50	-	1	-	-	-	-	-	-	-	-	-	-	6
7/10	50	3 albacore examined, all < 5 ml.												< 5
7/24	66	-	3	-	-	-	-	-	-	-	-	-	-	10
7/24	66	16 albacore examined, all < 5 ml.												< 5
7/29	81	3 albacore examined, all < 5 ml.												< 5
7/30	83	37 albacore examined, all < 5 ml.												< 5
8/8	102	3 albacore examined, all < 5 ml.												< 5

Table 10.--Field examination of albacore stomach contents, John R. Manning (cruise 36) (cont'd)
Troll-caught fish, (S = < 5 inches, M = 5-10 inches, L = > 10 inches)

Date 1957	Zone time of capture	Squid			Saury			Other fish			Plankton		Unidentifiable remains	Volume ml.
		S	M	L	S	M	L	S	M	L	Shrimp-like	Copepod and amphipod-like		
6/19	1615	9	-	-	-	-	-	4	-	-	2	-	x	35
6/19	1635	-	-	-	-	-	-	-	-	-	-	-	-	< 5
6/20	1930-2005 1/	-	-	-	-	-	-	1	-	-	-	3	x	10
6/20	"	-	-	-	-	-	-	-	-	-	-	-	x	< 5
6/21	0655-1922	-	-	-	-	-	1	1	-	-	-	-	x	45
6/21	"	-	-	-	3	-	-	14	-	-	-	-	-	15
6/21	"	-	-	-	-	-	-	-	-	-	-	-	-	< 5
6/22	1700	-	-	-	2	-	-	4	-	-	-	-	x	20
6/22	"	-	-	-	2	-	-	2	-	-	1	-	x	15
6/23	1130-1830	-	-	-	-	-	-	2	1	-	-	-	x	10
6/23	"	-	-	-	-	1	-	3	-	-	-	-	x	20
6/23	"	-	-	-	6	-	-	-	-	-	-	-	x	35
6/23	"	-	-	-	-	3	1	-	-	-	-	-	-	40
6/23	"	-	-	-	3	-	-	-	-	-	-	-	-	10
6/25	0830-1930	4	-	-	-	-	-	-	-	-	1	-	x	10
6/25	"	-	-	-	4	-	-	-	-	-	-	-	x	10
6/25	"	-	3	-	2	-	-	-	-	-	-	-	x	25
6/25	"	-	-	-	9	-	-	-	-	-	-	-	-	15
6/25	"	-	-	-	-	-	1	-	-	-	-	-	x	20
6/25	"	-	-	-	-	-	-	-	-	-	-	-	x	< 5
6/25	"	-	-	-	2	-	-	-	-	-	-	-	x	6
6/27	1510	-	-	-	-	-	-	-	-	-	-	-	-	< 5
6/30	1705	1	-	-	-	-	-	2	-	-	-	1	-	5
7/1	0855-1315	-	1	-	-	-	-	-	-	-	1	-	-	15
7/1	"	-	1	-	-	-	-	-	-	-	-	-	x	8
7/2	1120	-	-	-	-	-	-	-	-	-	-	-	-	< 5
7/2	1620	-	-	-	-	-	-	-	-	-	-	-	-	< 5
7/2	1645	-	-	-	-	-	-	-	-	-	-	-	-	< 5
7/2	1750	-	-	-	-	-	-	-	-	-	-	-	-	< 5
7/2	"	-	-	-	-	-	-	-	-	-	-	-	-	< 5
7/2	1620	-	-	-	-	-	-	-	-	-	-	-	-	< 5
7/3	0920	-	-	-	-	-	-	-	1	-	-	-	-	7
7/6	1615	-	-	-	11	-	-	-	-	-	-	-	-	20
7/6	"	-	-	-	13	-	2	-	-	-	-	-	-	80
7/6	"	-	-	-	-	-	-	-	-	-	-	-	-	< 5

1/ Exact time of capture not determined.

Table 10.--Field examination of albacore stomach contents, John R. Manning (cruise 36) (cont'd)
Troll-caught fish (S = < 5 inches, M = 5-10 inches, L = >10 inches) (cont'd)

Date 1957	Zone time of capture	Squid			Saury			Other fish			Plankton		Unidentifiable remains	Volume ml.
		S	M	L	S	M	L	S	M	L	Shrimp-like	Copepod and amphipod-like		
7/7	1625	-	-	-	-	-	1	-	-	-	-	-	-	25
7/8	0610	-	-	-	3	-	-	-	-	-	-	-	-	6
7/8	0710	-	-	-	6	-	-	-	-	-	-	-	-	11
7/8	"	-	-	-	-	-	-	-	-	-	-	-	-	< 5
7/8	0745	-	-	-	4	5	-	-	-	-	-	-	-	30
7/8	"	-	-	-	7	-	-	-	-	-	-	-	-	12
7/8	1100	-	-	-	-	-	-	-	-	-	-	-	-	< 5
7/8	"	-	-	-	-	-	-	-	-	-	-	-	-	< 5
7/10	0920	-	-	-	-	-	1	-	-	-	-	-	x	38
7/10	"	-	-	-	-	-	-	-	-	-	-	-	-	< 5
7/10	1035	-	-	-	-	-	-	-	-	-	-	-	-	< 5
7/10	1140	-	-	-	-	2	1	-	-	-	-	-	x	15
7/10	1142	-	-	-	-	-	-	-	-	-	-	-	-	< 5
7/12	1650	5	-	-	-	-	-	1	-	-	-	-	-	10
7/14	0700	-	-	-	-	-	-	-	-	-	-	-	-	< 5
7/14	1615	-	-	-	-	-	-	-	-	-	-	-	-	< 5
7/14	1745	-	-	-	-	-	1	-	-	-	-	-	x	10
7/14	1820	-	-	-	-	7	-	-	-	-	-	-	-	50
7/14	1904	-	-	-	-	-	-	-	-	-	-	-	-	< 5
7/14	2022	-	-	-	3	-	-	-	-	-	-	-	-	7
7/14	2035	3	-	1	-	3	-	-	-	-	-	-	x	40
7/23	1235	-	1	-	-	-	-	-	-	-	-	-	x	5
7/23	0635	-	-	-	-	-	-	-	-	-	-	-	-	< 5
7/23	0753	-	-	-	1	-	-	-	-	-	-	-	x	< 5
7/23	0635	-	-	-	-	-	-	-	-	-	-	-	-	< 5
7/23	0845	-	-	-	-	-	-	-	-	-	-	-	x	20
7/23	1235	-	-	-	-	-	-	-	-	-	-	-	x	15
7/23	1450	-	-	-	-	-	-	-	-	-	-	-	-	< 5
7/23	1920	-	-	-	-	-	-	-	-	-	-	-	-	< 5
7/23	2000	-	-	-	-	-	-	-	-	-	-	-	-	< 5
7/24	1930	-	-	-	-	2	-	-	-	-	-	-	-	8
7/25	1545	-	-	-	-	-	-	-	-	-	-	-	-	< 5
7/25	1950	-	1	-	-	-	-	-	-	-	-	-	-	6
7/28	0610	-	-	-	-	-	-	4	-	-	-	-	-	15
7/28	0640	3	-	-	-	-	-	6	-	-	-	-	x	15
7/28	1545	-	-	-	-	-	-	-	-	-	-	-	-	< 5
7/28	0705	-	-	-	-	-	-	-	-	-	-	-	-	< 5

Table 10.--Field examination of albacore stomach contents, John R. Manning (cruise 36) (cont'd)
Troll-caught fish (S = < 5 inches, M = 5-10 inches, L = > 10 inches) (cont'd)

Date 1957	Zone time of capture	Squid			Saury			Other fish			Plankton		Unidentifiable remains	Volume ml.
		S	M	L	S	M	L	S	M	L	Shrimp-like	Copepod and amphipod-like		
7/29	0930	-	-	-	-	-	-	-	-	-	-	-	-	< 5
8/3	0830	-	-	-	-	-	-	-	8	-	-	-	-	30
8/3	1045	-	-	-	1	-	2	-	-	-	-	-	-	110
8/3	"	-	-	-	-	1	-	-	-	-	-	-	-	30
8/3	"	-	-	-	2	-	3	-	-	-	-	-	-	273
8/4	1135	-	-	-	-	-	-	-	-	-	-	-	-	< 5
8/4	1630	-	-	-	-	-	-	-	2	-	-	-	-	12
8/5	0850	-	-	-	-	-	-	-	-	-	-	-	-	< 5
8/6	0600	-	-	-	-	-	-	-	-	-	-	-	-	< 5
8/6	1112	-	-	-	-	-	-	-	1	-	-	-	x	8
8/10	0610	-	-	-	-	-	-	-	-	-	-	-	-	< 5

Table 11.--Albacore holding experiments, John R. Manning (cruise 36)

Date 1957	Length of troll line (feet)	Time placed in tank	Time of death	Survival time hours	Remarks
7/23	150	2000	2030	1/2	
7/23	150	1920	2030	1-1/4	
7/24	135	0930	0945	1/4	Lampblack applied to the eyes.
7/24	65	0930	0945	1/4	" " " " "
7/24	90	1445	1500	1/4	
7/24	90	1530	2000	4-1/2	
7/25	65	1615	0300-0700, 7/26[1/]	10-3/4 - 14-3/4	Jumped out of tank. Rough weather
7/26	150	1945	1950	< 1/4	
7/27	150	1630	2130	5	Artificial respiration with hose
7/28	150	0610	0815	1/2	
7/28	80	0640	1045	3	No separate tally kept on individual fish.
7/28	90	0640	1045	3	No line assigned for individual fish.
7/28	65	0640	1500	7-1/4	Survival time figured from 0745.
7/28	65	0745	2200	14-1/4	

[1/] Exact time of death not determined.

Table 12.--Night-light observations of sauries by the Hugh M. Smith (cruise 40)

Date 1957	Zone time[1/]	North latitude	West longitude	Numbers estimated	Estimated length in inches
7/17	2030	45°54'	125°27'	1,000	6
7/23	0020	47°02'	127°10'	0	-
	0200	47°02'	127°08'	0	-
	2200	47°00'	129°08'	1,000	4-8
7/24	0100	47°00'	129°08'	1,000	1-14
	0430	47°02'	129°09'	1,000	1-14
7/25	0200	46°46'	130°46'	0	-
7/29	0200	45°12'	126°46'	0	-
	0400	45°10'	126°44'	1,000	3-4
7/30	0230	43°49'	124°43'	1,000	3-4
7/31	0000	42°55'	127°01'	10	2
	0200	42°53'	127°02'	1,000	3-4
	0400	42°51'	127°02'	0	-
8/1	0200	42°13'	129°08'	0	-
	0500	42°10'	129°09'	10	3-4
8/2	0200	41°33'	130°41'	50	1-3
	0430	41°31'	130°44'	0	-
	0445	41°31'	130°44'	1	14
8/3	0200	41°17'	128°19'	0	-
8/4	0000	40°58'	126°00'	10	3
	0200	40°52'	125°57'	6	4-6
	2355	40°25'	126°16'	0	-
8/5	0200	40°25'	126°19'	0	-
	0435	40°23'	126°21'	0	-
8/7	0200	39°30'	131°00'	0	-
	2355	39°07'	128°40'	0	-
8/8	0200	39°06'	128°40'	0	-
8/9	0000	39°03'	127°00'	0	-
	0200	39°05'	126°55'	0	-
8/10	0000	38°56'	124°24'	0	-
	0200	38°54'	124°22'	1	5
8/13	0000	37°09'	128°35'	0	-
	0200	37°06'	128°32'	0	-
8/14	0000	36°51'	126°33'	0	-
	0200	36°49'	126°31'	0	-
	0430	36°46'	126°28'	0	-

[1/] Consult the Standard Time Chart of the World (HO 5192) of the U. S. Hydrographic Office for zone boundaries.

Table 13.--Night-light observations by the John R. Manning (cruise 36)

Date 1957	Position		Present not persistent	Numbers persistent under the lights			Approximate size	
	North latitude	West longitude		1-5	6-10	11-30	Sauries	Squids
6/18	36°10'	142°52'	-	Myctophids	-	-	-	-
				Squids	-	-	-	> 12 inches
6/19	36°53'	141°41'	Myctophids	Sauries	-	-	< 4 inches	-
				Squids	-	-	-	> 12 inches
6/21	39°43'	138°09'	Sauries	-	-	-	-	-
			Squids	-	-	-	-	> 12 inches
6/24	39°57'	134°56'	-	Sauries	-	-	< 4 inches	-
6/25	38°30'	134°35'	Myctophids	Sauries	-	-	-	-
			Squids	-	-	-	-	> 12 inches
6/26	36°49'	133°51'	Sauries	-	-	-	< 4 inches	-
			Myctophids	-	-	-	-	-
7/1	34°25'	126°26'	Sauries	-	-	-	< 4 inches	-
			Squids	-	-	-	-	> 12 inches
7/5	36°37'	130°12'	Sauries	-	-	-	4-8 inches	-
7/6	37°19'	129°10'	Sauries	-	-	-	-	-
7/9	39°59'	126°51'	-	-	-	-	-	-
7/23	43°42'	127°53'	-	-	Sauries	-	-	-
/28	38°45'	128°37'	Sauries	-	-	-	-	-
			Myctophids	-	-	-	-	-
/29	39°00'	127°31'	Squids	-	-	Sauries	-	> 12 inches
			Myctophids	-	-	-	-	-
/2	39°06'	127°31'	-	-	-	-	-	-
/7	36°08'	123°29'	Sauries	-	-	-	-	-
			Myctophids	-	-	-	-	-
/8	34°48'	123°22'	Sauries	-	-	-	-	-
			Squids	-	-	-	-	-

Table 14.--Night-light observations by the charter vessels

Date 1957	North latitude	West longitude	Sauries	Myctophids	Miscellaneous
Flicker					
7/22	42°20'	127°00'	Abundant	0	Ctenophora Pteropods
7/23	42°20'	128°45'	Abundant	0	Amphipods Salpa chains Pteropods
7/24	42°20'	130°45'	Abundant	20	2 salpa types 1 velella 1 invertebrate ?
7/26	42°00'	133°00'	Few	0	Weather rough
7/27	41°40'	131°40'	Few	1	-
7/28	41°30'	129°55'	Few	0	Salpa chains
7/29	41°32'	128°25'	Moderate	2	Salpa chains
7/30	41°40'	127°00'	Abundant	9	1 jellyfish
Roland R. Sr.			Luminescence		Bait
7/22	39°45'	124°40'	Very little		None
7/23	39°43'	127°50'	Very little		None
7/24	39°44'	129°20'	Very little		None
7/25	39°48'	131°00'	None		None
7/26	39°47'	132°20'	None		None
7/27	39°00'	131°48'	None		None
7/28	38°56'	130°51'	None		None
7/29	39°05'	129°13'	None		None
7/30	39°03'	127°41'	Small amount		None
7/31	39°05'	129°44'	None		None

Date 1957	Zone time[1/]	Noon position		Fish	Bird flocks	Aquatic mammals
		North latitude	West longitude			
7/4	1703	26°39'	152°42'	25 flying fish	-	-
	1730			-	-	1 whale
7/10	1229	42°20'	140°09'	1 sunfish	-	-
7/11	0700	44°39'	137°52'	-	Petrels (< 10)	-
	0805 through 1440			-	Many small unidentified birds	-
7/12	1143	44°02'	136°29'	-	-	5 porpoise
	1603			-	-	30 porpoise
7/16	1639	44°51'	130°01'	-	-	1 whale
7/18	0935	46°16'	124°16'	Medium-size, unidentified school	Petrels (11-50)	-
7/22	0911	46°59'	126°08'	-	-	2 porpoise
	1645			-	-	1 whale
	1655			1 great blue shark	-	-
7/23	0630	47°00'	127°47'	1 great blue shark	-	-
	1400			Albacore tuna school	-	-
7/24	1440	46°45'	130°14'	1 shark	-	-
	1647			Albacore tuna school	-	-
7/25	1115	46°46'	131°57'	-	-	1 seal
	1709			-	-	1 whale
7/26	1445	46°37'	133°04'	-	Snipes (?) (> 50)	-
	2010			-	-	1 seal
7/29	1535	44°25'	125°59'	-	-	1 whale
	1540			1 sunfish	-	-
	1550			-	-	4 whales
	1607			1 sunfish	-	-
	1730			Small-size school of anchovies (dead and floating)	-	-
	1835			1 sunfish	-	-
	1840			-	-	25 whales
	1945			-	-	6 porpoise
7/30	0635	43°22'	129°59'	-	-	3 whales
	0709			-	-	4 whales
	0810			1 great blue shark	-	-
	0853			1 great blue shark	-	-
				1 manta		

[1/] Consult the Standard Time Chart of the World (HO 5192) of the U. S. Hydrographic Office for zone boundaries.

Table 15.--Fish, bird flocks, and aquatic mammals sighted from the Hugh M. Smith (cruise 40) (cont'd)

Date 1957	Zone time[1]	Noon position		Fish	Bird flocks	Aquatic mammals
		North latitude	West longitude			
7/30	0910	43°22'	129°59'	-	-	Porpoise school
	0920			-	-	12 porpoise
	1720			-	-	35 porpoise
	1925			-	-	2 whales
8/1	0810	41°51'	131°04'	1 sunfish	-	-
	1925			1 sunfish	-	-
8/3	1720	41°05'	127°00'	1 great blue shark	-	-
	1735			-	-	2 whales
8/4	0635	40°44'	125°08'	1 sunfish	-	-
	0715			-	-	Porpoise school
	1128			-	-	6 porpoise
	1205			-	-	12 porpoise
	1247			-	-	1 porpoise
8/9	0835	39°10'	125°41'	1 great blue shark	-	-
	0845			-	Snipes (?) (11-50)	-
	0916			-	Snipes (?) (11-50)	-
8/11	0652	38°04'	127°41'	Large-size school of bait fish	-	-
8/13	1015	37°01'	127°38'	-	Snipes (?) (11-50)	-
	1638			-	-	1 whale
8/14	0655	36°58'	125°32'	1 great blue shark	-	-
8/26	1530	San Francisco		-	-	1 killer whale
8/27	0759	37°19'	123°07'	-	-	3 sperm whales
8/29	0700	32°14'	130°17'	-	-	2 sperm whales
	1125			-	-	6 porpoise
	1305			-	-	15 porpoise
8/30	1242	30°48'	134°09'	-	-	Large school of porpoise
	1642			-	-	2 whales
8/31	1617	29°16'	138°11'	Medium-size school of skipjack tuna	-	-
9/3	1635	24°43'	145°28'	-	-	1 sperm whale
9/4	0530	23°08'	153°12'	20 flying fish	-	-
	0600			50 flying fish	-	-
	1545			Small-size school of skipjack tuna	(11-50) petrels or shearwaters	-

[1] Consult the Standard Time Chart of the World (HO 5192) of the U. S. Hydrographic Office for zone boundaries.

Table 16.--Fish, bird flocks, and aquatic mammals sighted from the John R. Manning (cruise 36)

Date 1957	Zone time[1]	Noon position		Fish	Bird flocks	Aquatic mammals
		North latitude	West longitude			
6/12	0730	22°33'	156°45'	-	Terns (< 10)	-
	1215			1 flying fish	-	-
6/13	1250	24°42'	154°21'	1 flying fish	-	-
	1305			100 flying fish	-	-
6/14	1210	26°48'	152°14'	3 flying fish	-	-
6/17	0730	33°35'	145°19'	Medium-size school of large unidentified fish	-	-
	0845			-	-	1 sperm whale
6/20	1650	37°09'	141°15'	Small-size school of flying fish	-	-
6/21	0845	39°18'	138°39'	Large-size school of albacore tuna	-	-
	1110			Large-size school of albacore tuna, 15-20 pound fish	-	-
6/22	0835	40°09'	137°27'	-	Petrels (< 10)	-
	0930			-	Petrels (< 10)	-
	1005			-	Petrels (< 10)	-
6/23	1240	41°29'	135°05'	-	Petrels (< 10)	-
	1420			-	-	1 whale
7/1	1320	34°02'	127°12'	-	-	1 whale
	1625			1 flying fish	-	-
7/7	1310	37°32'	128°53'	-	Shearwaters (< 10)	-
7/12	1341	40°03'	133°03'	-	-	3 porpoise
7/13	1705	41°42'	130°22'	1 sunfish	-	-
7/14	1750	42°49'	128°26'	Albacore tuna school	Shearwaters (< 10)	-
7/15	1035	44°32'	126°28'	-	-	1 whale
	1645			1 shark	-	-
7/26	1645	40°47'	131°20'	1 shark	-	-
7/29	1230	38°56'	127°05'	-	-	8 whales
7/31	1205	38°59'	127°28'	2 sunfish	-	6 killer whales
8/3	1645	38°48'	127°09'	Large school of saury	-	-
	1740			-	-	1 whale
8/5	0930	38°05'	125°25'	-	-	1 humpback whale
	0935			1 sunfish 1 shark	-	-

[1] Consult the Standard Time Chart of the World (HO 5192) of the U. S. Hydrographic Office for zone boundaries.

Table 16.--Fish, bird flocks, and aquatic mammals sighted from the John R. Manning (cruise 36) (cont'd)

Date 1957	Zone time[1]	Noon position		Fish	Bird flocks	Aquatic mammals
		North latitude	West longitude			
8/5	1200	38°05'	125°25'	School of bait	-	6 porpoise
	1242			Large school of bait	-	-
	1335			2 great blue shark	-	1 porpoise
	1419			-	-	4 porpoise
	1425			1 great blue shark	-	-
8/8	1305	35°44'	123°24'	-	-	1 seal
	1423			-	-	10 porpoise
8/9	0815	34°48'	123°54'	-	-	2 porpoise
8/10	1740	34°16'	126°21'	1 flying fish	-	-
8/15	0720	28°28'	142°56'	2 large schools of flying squid	-	-
	0800			Flying squid	-	-
	0820			Flying squid	-	-
	0905			Flying squid	-	-
	0935			Flying squid	-	-

[1] Consult the Standard Time Chart of the World (HO 5192) of the U. S. Hydrographic Office for zone boundaries.

Table 17.--Fish, birds, and aquatic mammals sighted from charter vessels

Date 1957	Noon position		Daily summary of observations
	North latitude	West longitude	
			Lancing
/22	45°03'	126°22'	A few birds
/23	44°06'	128°18'	3 albatross
/24	43°05'	129°05'	2 groups of unidentified fish or whales, 4 to 8 in each group
/31	44°20'	126°13'	A few small birds, 1 whale
			Gypsy
/27	43°28'	133°25'	Some feed and porpoise
/29	42°56'	130°20'	2 albatross
/30	43°02'	128°37'	2 albatross
/31	42°56'	126°51'	Albatross
/1	42°50'	125°36'	Several fish sighted
			Flicker
/26	42°22'	132°34'	20 small sandpiper-like birds
/27	41°40'	132°39'	2 small whales, 10 killer whales
/28	41°36'	130°53'	6-foot great blue shark, bait breaking the surface
/29	41°30'	129°13'	Medium-size sunfish
/30	41°36'	127°45'	Small brownish to black whale
/31	41°40'	126°18'	44 porpoise, 1 large whale
			Lynn Ann
/22	41°00'	125°43'	1 albatross, 3 petrels, 2 whales, 3 unidentified birds
/25	41°00'	130°17'	A few albatross and petrels
/26	40°55'	131°26'	1 albatross, 2 petrels
/27	41°00'	133°00'	2 albatross, 1 petrel
/28	40°20'	131°54'	8 petrels, 1 shearwater, 2 albatross
/29	40°20'	130°19'	3 killer whales, 1 petrel
/30	41°26'	128°27'	12 petrels, 6 albatross, 4 unidentified birds, at one instance during the day 20 birds were sitting on the water
/31	40°22'	126°42'	5 porpoise, 4 great blue sharks, 9 petrels, 1 shearwater, 35 unidentified birds
			Rowland R. Sr.
22	39°37'	125°35'	15 porpoise
25	40°00'	130°10'	1 petrel
26	39°43'	131°24'	Sauries jumping, 9 petrels, 2 albatross
27	39°20'	132°10'	7 petrels, 1 albatross
28	38°45'	131°57'	6 petrels, 1 albatross
29	39°00'	130°05'	7 albatross, 2 petrels
30	38°52'	128°25'	Small school of bait, 18 to 20 fish, 3 inches in length; sauries, 3 inches in length, 1 albatross, 1 petrel
31	38°55'	127°22'	1 petrel, 1 shearwater
			Allen Cody
24	38°18'	126°32'	Whales and sharks
31	37°35'	126°16'	Large school of whales, some small fish

Table 17.--Fish, birds, and aquatic mammals sighted from charter vessels (cont'd)

Date 1957	Noon position		Daily summary of observations
	North latitude	West longitude	
			Luwella
7/23	35°45'	123°37'	1 albatross
7/24	35°32'	124°39'	1 albatross
7/25	35°35'	125°14'	1 albatross, 1 petrel
7/27	35°45'	129°24'	2 albatross, 2 petrels
7/28	35°02'	128°25'	2 albatross, 1 shearwater
7/29	35°07'	126°47'	3 albatross, 1 petrel, 2 unidentified birds, 1 flying fish
7/30	34°52'	125°00'	2 albatross, 2 petrels, 1 tropic bird
7/31	34°55'	123°20'	Jumping sauries, 1 shark, 1 petrel, 1 unidentified bird
8/1	34°49'	121°48'	10 porpoise, 20 to 30 sunfish, 2 sharks, 2 petrels, 8 to 10 unidentified birds

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U. S. DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
SEP. NO. 556

August 1959 Washington 25, D.C. Vol. 21, No. 8

CONSTRUCTION AND CATCH SELECTIVITY OF ALBACORE GILL NETS USED IN THE CENTRAL NORTH PACIFIC

By Joseph J. Graham* and Herbert J. Mann**

CONTENTS

Introduction 1
Type of Gear Used 2
Selectivity of Mesh Size 3
Summary 6
Literature Cited 6

INTRODUCTION

A comprehensive study of the resources of the albacore tuna, Germo alalunga (Bonnaterre), north and northeast of the Hawaiian Island chain under Public Laws 329 and 466 (the latter known as the Saltonstall-Kennedy Act) has been made by the Pacific Oceanic Fisheries Investigations (POFI) of the U. S. Bureau of Commercial Fisheries. One of the important objectives of the study has been to uncover concentrations of albacore of commercial magnitude. It is likely such a concentration was brought to light by cruises in 1955 and 1956 (fig. 1).

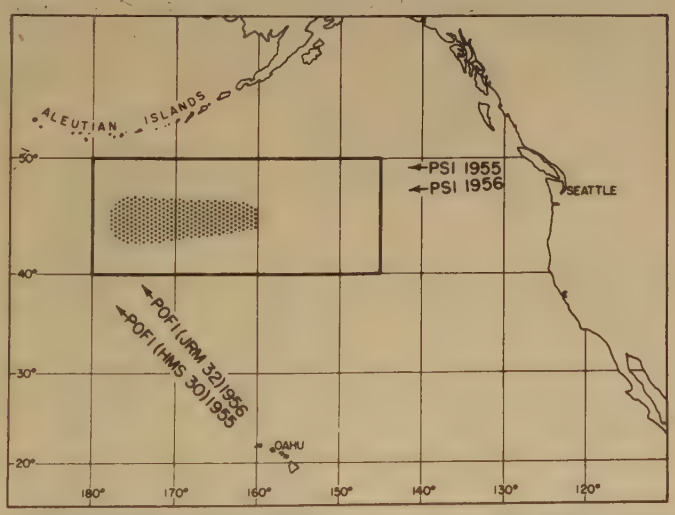

Fig. 1 - Outline of the general region surveyed during 1955 and 1956 by Pacific Oceanic Fishery Investigations and Pacific Salmon Investigations. The area of albacore concentrations is shaded.

The principal gear that made this discovery possible was the gill net, and events leading up to its use by POFI in the North Pacific began in 1955. During the summer of that year, the POFI research vessel Hugh M. Smith (cruise 30) surveyed the central North Pacific (fig. 1) with vessels of Pacific Salmon Investigations (PSI) of the U. S. Fish and Wildlife Service (Powell and Peterson 1957). The Hugh M. Smith conducted hydrographic stations while determining the distribution and abundance of albacore tuna with trolling gear. The PSI vessels attempted to delineate the distribution of high-seas salmon by gill-netting at night. Catches of albacore on the trolling gear were mediocre. However, albacore were taken in the salmon gill nets at the more southern stations (48° N.-45° N.) of the PSI vessels. A few of those catches were impressive, particularly since most of the fish were not gilled, but entangled in the small-meshed salmon nets 1/. The following year, during the same period and in the same area, the POFI research vessel John R. Manning made a fishing survey (cruise 32) in cooperation with PSI. Gill-netting was extended farther south (43° N.) by POFI where a greater abundance of albacore was anticipated and larger mesh sizes more suitable for albacore were used. Again albacore were found concentrated in about the same area, and were taken in that vessel's gill nets in near-commercial quantities.

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1/ Personal communication to Director, POFI, Honolulu, T.H., from Chief, Pacific Salmon Investigations, Seattle, Wash., September 20, 1955.

TYPE OF GEAR USED

The gill nets fished by POFI were of a design currently in use in the salmon fishery of the northwest coast of America. In addition, trammel nets designed specifically by POFI gear specialists for albacore fishing were utilized. The construction details of both types of nets are shown in figure 2. A unit of gear, the

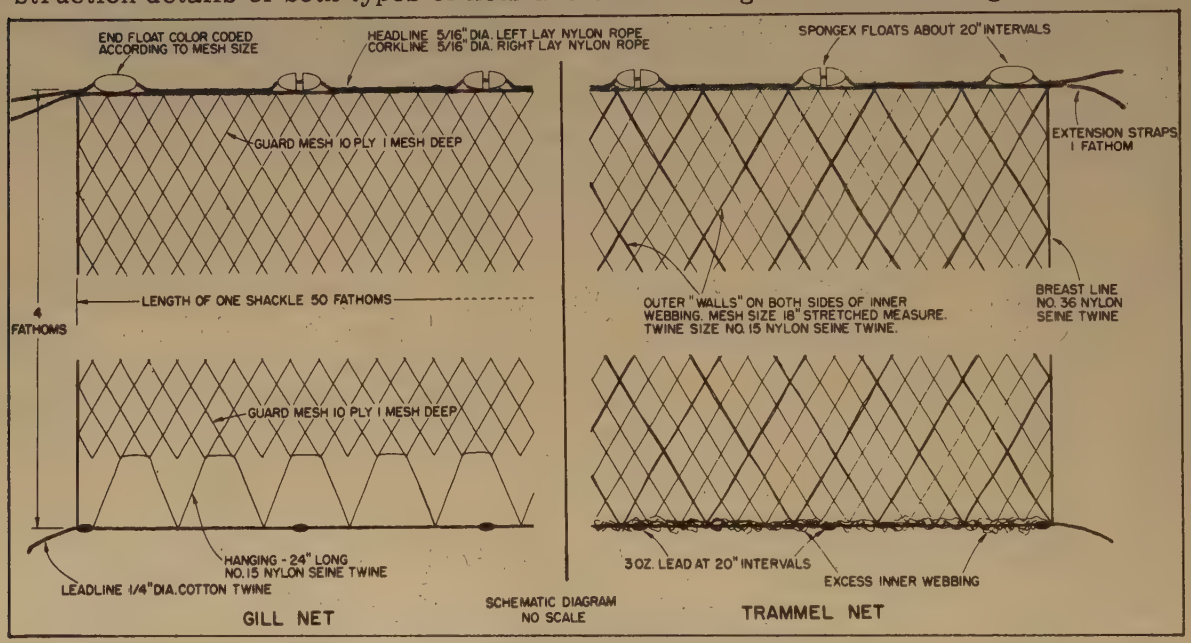
END FLOAT COLOR CODED ACCORDING TO MESH SIZE
HEADLINE 5/16" DIA. LEFT LAY NYLON ROPE
CORKLINE 5/16" DIA. RIGHT LAY NYLON ROPE
GUARD MESH 10 PLY 1 MESH DEEP
LENGTH OF ONE SHACKLE 50 FATHOMS
4 FATHOMS
GUARD MESH 10 PLY 1 MESH DEEP
HANGING - 24" LONG NO.15 NYLON SEINE TWINE
LEADLINE 1/4" DIA.COTTON TWINE
GILL NET
SCHEMATIC DIAGRAM NO SCALE
SPONGEX FLOATS ABOUT 20" INTERVALS
EXTENSION STRAPS 1 FATHOM
OUTER "WALLS" ON BOTH SIDES OF INNER WEBBING. MESH SIZE 18" STRETCHED MEASURE. TWINE SIZE NO. 15 NYLON SEINE TWINE.
BREAST LINE NO. 36 NYLON SEINE TWINE
3 OZ. LEAD AT 20" INTERVALS
EXCESS INNER WEBBING
TRAMMEL NET

Fig. 2 - Construction details of POFI albacore nets.

shackle, measured 50 fathoms in length and about 4 fathoms in depth regardless of mesh size. A set at a gill-net station was composed of 12 shackles of gill net and 2 shackles of trammel net joined together. The mesh sizes of the gill-net shackles

Table 1 - Gill-Net Specifications

Mesh Size (Stretched)	Depth (Number of Meshes)	Twine Size (Ply)	Guard Mesh (Size and Ply)	Type Hanging (Leadline)
$4\frac{1}{2}$	71	5	1 mesh-10 ply, 1 mesh-8 ply	2 mesh/hanging, skip 1
$5\frac{1}{2}$"	59	5	"	"
$6\frac{1}{2}$"	51	6	"	"
$7\frac{1}{2}$"	45	8	"	2 mesh/hanging, skip 0

were $4\frac{1}{2}$ inches, $5\frac{1}{2}$ inches, $6\frac{1}{2}$ inches, and $7\frac{1}{2}$ inches (stretched mesh). Construction details of the gill-net and trammel-net shackles are summarized in tables 1 and 2, respectively. Nets were hung in a conventional manner with the webbing 50 percent

Table 2 - Trammel-Net Specifications

Inner Net			Outer Net		
Mesh Size (Stretched)	Depth (Number of Meshes)	Twine Size (Ply)	Mesh Size (Stretched)	Depth (Number of Meshes)	Twine Size (Number)
$4\frac{1}{2}$"	124	5	18"	20	15
$6\frac{1}{2}$"	86	6	19"	19	15

on the corkline so that 100 fathoms of netting (stretched mesh) were hung on 50 fathoms of corkline. Trammel nets differed from the gill nets in the addition of large-mesh outer "walls," which enclosed the inner webbing. These outer walls of webbing were evenly spaced opposite to each other to allow fish to push the inner webbing through the walls and thus pocket themselves.

Except for the leadline, the nets were made of nylon, and dyed green or grey-green to make them less conspicuous in the water. The webbing was constructed of bonded double-knotted salmon twine, headlines and corklines of 3-strand spun rope, and breastlines, seizings, and hangings of spun twine.

SELECTIVITY OF MESH SIZE

The manner in which albacore were captured during the summer cruise of the John R. Manning was not the same for the various meshes of a set. Smaller meshes of the gill nets captured fish more by entangling than gilling and the trammel meshes captured entirely by entangling rather than pocketing. When a set of nets was retrieved, the tension placed on the shackle coming aboard was sufficient to disentangle the fish and those not properly gilled sometimes fell out of the net before reaching the vessel. Table 3 indicates that more fish were lost from the smaller meshes than from the nets of larger meshes during retrieving. The absence of fish loss from the trammel mesh probably attests to the entangling efficiency of its multiple meshes.

Table 3 - The Number of Fish Lost per Mesh Size of Gill Net as the Retrieved Gear Neared the Vessel
(The figures in parentheses give the loss per shackle.)

Mesh	$4\frac{1}{2}$"	$5\frac{1}{2}$"	$6\frac{1}{2}$"	$7\frac{1}{2}$"
Number Lost .	7(0.21)	11(0.25)	5(0.09)	1(0.03)

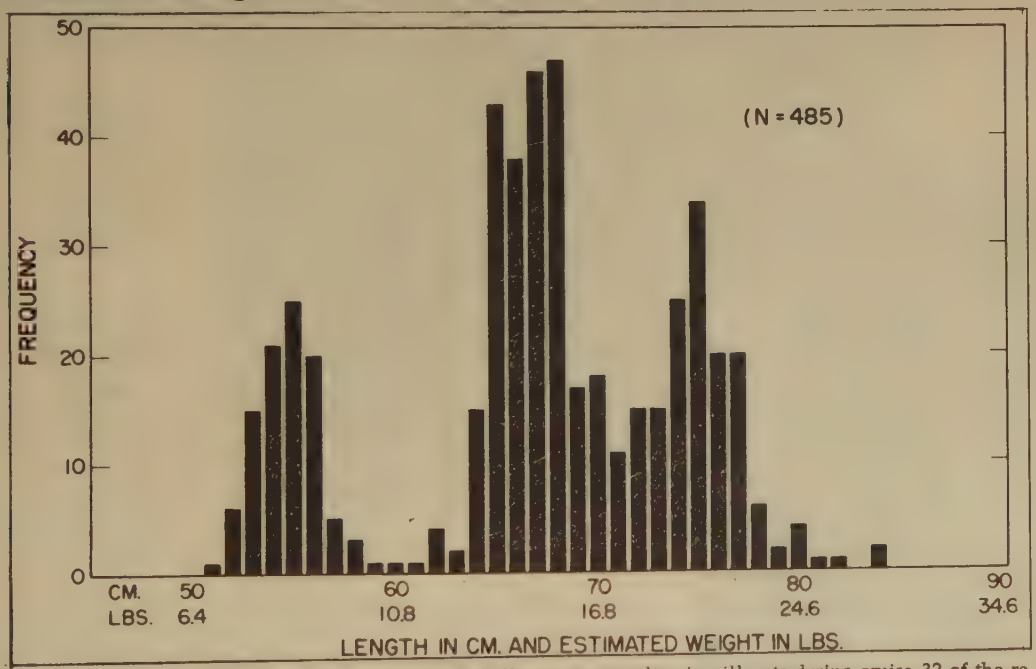

Fig. 3 - Length frequencies and estimated weight of albacore tuna taken in gill nets during cruise 32 of the research vessel John R. Manning.

Three size groups of albacore covering a size range of 51 cm. (20 inches) to 84 cm. (33 inches) fork length (fig. 3) were sampled by the gill nets of the John R. Manning. Table 4 shows that over this size range a progressive shift toward larger

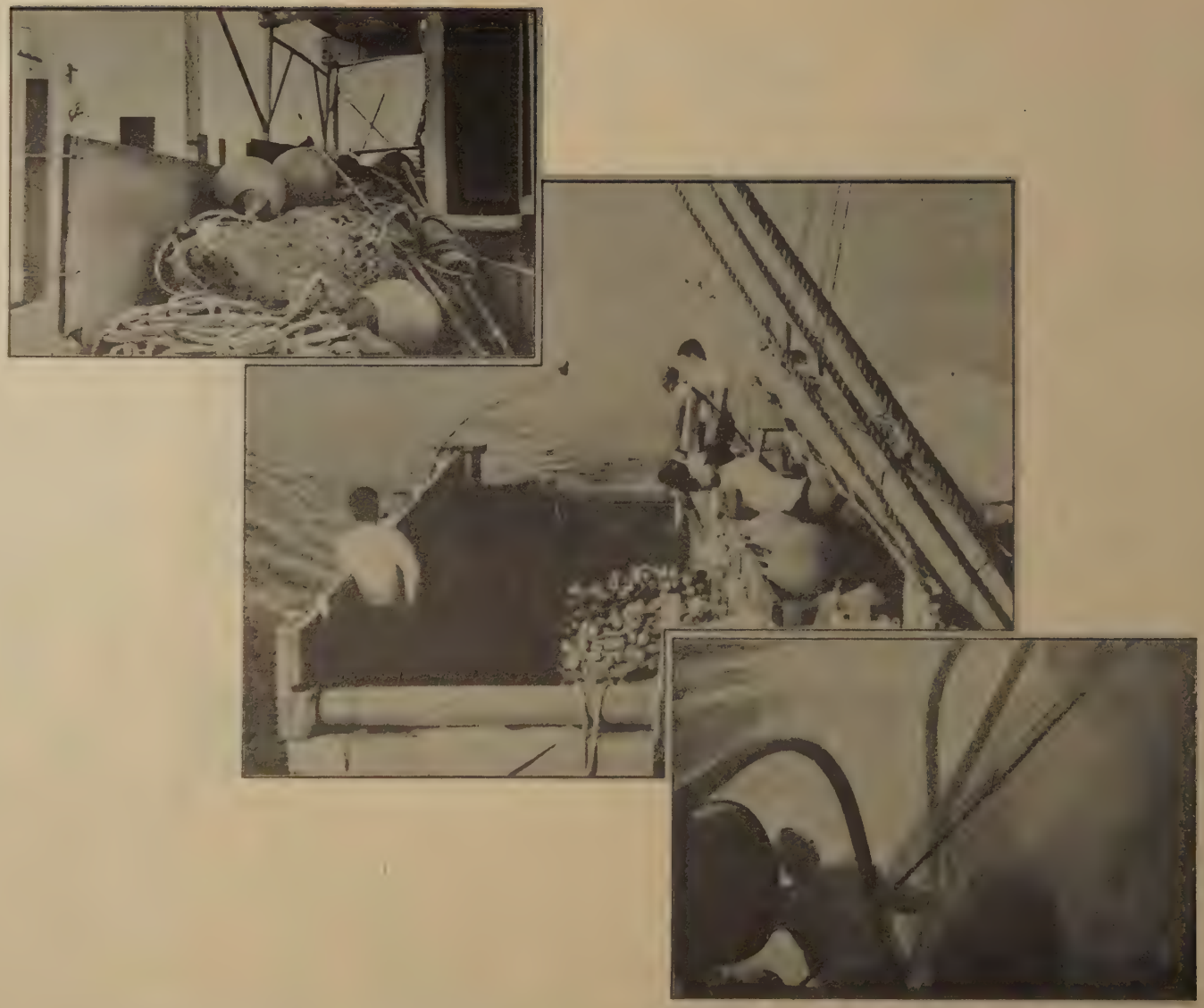

Fig. 4 - Upper left panel: Gill nets stacked in the bins of the charter vessel Paragon. Middle panel: Laying gill nets, John R. Manning. Bottom panel: Retrieving gill nets in the North Pacific, John R. Manning.

fish accompanied an increase in mesh sizes from $5\frac{1}{2}$ inches to $7\frac{1}{2}$ inches. This shift was so great in the case of the largest mesh that the small size group (51-60 cm. or 20-23 inches) was almost missing from the catch. In contrast, the smallest mesh ($4\frac{1}{2}$ inches) captured fish from all three size groups sampled (51-60 cm. or 20-23 inches, 61-70 cm. or 24-28 inches, and 71-80 cm. or 28-31 inches) and small fish were not emphasized in the catch. As in the case of the trammel nets it appeared that the $4\frac{1}{2}$-inch mesh captured albacore entirely by entangling.

Table 4 - Length Frequency of Albacore per Mesh Size

Shackel	Fork Length in cm.																															Totals
	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	
$4\frac{1}{2}$	-	-	1	3	2	6	-	-	-	1	-	-	-	2	5	8	4	3	4	-	1	-	1	3	3	5	3	1	-	-	-	-	-	1	57
$5\frac{1}{2}$	-	6	10	8	7	4	2	1	-	-	-	1	1	2	5	-	6	8	3	2	2	2	1	4	5	-	3	-	-	-	-	-	-	-	83
$6\frac{1}{2}$	1	-	2	9	14	6	3	2	-	-	1	3	-	7	19	18	21	16	6	11	6	4	4	4	12	6	4	1	-	2	-	-	-	-	182
$7\frac{1}{2}$	-	-	-	-	1	-	-	-	-	-	-	-	1	3	10	8	12	19	3	5	2	6	7	5	8	5	8	3	2	2	-	-	-	1	111
Trammel	-	-	2	1	1	4	-	-	1	-	-	-	-	1	3	4	3	1	1	-	-	3	2	7	5	4	2	1	-	-	1	-	-	-	47
Totals	1	6	15	21	25	20	5	3	1	1	1	4	2	15	42	38	46	47	17	18	11	15	15	23	33	20	20	6	2	4	1	-	-	2	480

The progressive shift in fish size with increase in mesh size and the ability of the larger meshes to gill rather than entangle affect the commercial potentialities of the individual meshes. Of the meshes fished, the $7\frac{1}{2}$ inch stands far above the others in efficiency in catch when measured both by numbers and by weight of fish caught per shackle (table 5). This efficiency is further emphazised in that average

Table 5 - Catch per Mesh Size Within the Area of Abundance (42°-46° N., 175°-155° W.)
(Figures in Parentheses were Determined from the Four Largest Catches 1/)

Mesh Size (Stretched Measure)	Albacore		Weight in Pounds			Percentage of Albacore Above 10 Lbs.	No. of Sharks	
	Total Number	Number Per Shackle	Total	Per Shackle	Avg. Fish		Total	Per Shackle
$4\frac{1}{2}$"	(35) 57	(4.4) 2.0	855	(61) 30	$15\frac{1}{2}$"	79	57	1.9
$5\frac{1}{2}$"	(48) 84	(4.8) 2.2	1,054	(56) 28	$12\frac{1}{2}$"	54	57	1.4
$6\frac{1}{2}$"	(105) 186	(8.0) 3.7	2,642	(110) 56	$14\frac{1}{2}$"	80	56	1.1
$7\frac{1}{2}$"	(78) 118	(9.8) 4.2	1,929	(172) 69	$17\frac{1}{2}$"	99	22	0.7
Trammel	(25) 47	(5.0) 2.8	773	(78) 45	$16\frac{1}{2}$"	80	28	1.6

1/ Included in all figures is the catch for a set which took 10 albacore, but had a soaking time of only $2\frac{1}{2}$ hours.

fish size is greater for this mesh and almost all fish taken exceeded 10 pounds. Below this size albacore are often not acceptable to canners. Another attractive feature of the larger mesh is a lower shark catch per shackle, for while shark damage to albacore during the cruise was negligible, their removal from the nets required time and resulted in broken meshes. Presumably, the larger mesh of the $7\frac{1}{2}$-inch net permitted the slender form of the great blue Prionace glauca (Linnaeus)--the most abundant shark--to pass through rather than gill in the net.

On the basis of the above data, it is not possible to establish what mesh size would be best for fishing albacore commercially with gill nets in the central North Pacific, since our most efficient mesh was also the largest used. Powell et al (1952) captured albacore of the same size range in the eastern North Pacific using gill nets with mesh sizes of $7\frac{1}{2}$ inches, $8\frac{1}{2}$ inches, and $9\frac{1}{2}$ inches. His data showed that the $7\frac{1}{2}$-inch and $8\frac{1}{2}$-inch meshes fished with about the same success but the $9\frac{1}{2}$-inch mesh experienced a considerable decrease in catch. From Powell's and our own observations we conclude that the most efficient mesh size with respect to commercial gain would lie between $7\frac{1}{2}$ inches and $8\frac{1}{2}$ inches.

As the gill net was retrieved aboard the John R. Manning, an observer recorded the depth of each albacore in the net by arbitrarily dividing the total depth of the

net (by sight) into thirds. A summary of these observations showed that during the cruise, 41 percent of the catch was taken in the upper third of the net, 35 percent in the middle, and 24 percent in the lower third. Thus, most of the fish were captured near the top of the net, but the one quarter near the bottom would suggest that if the net had been deeper, more fish might have been taken. Powell et al (1952) also recorded the depth distribution of fish in their nets and found that the majority of the albacore were taken near the surface between 1 and 3 fathoms in depth, that is, within the depth (4 fathoms) of the POFI nets. However, several fish were captured near the leadline and it is possible that in some instances the 100-mesh nets, which are about twice the depth of the POFI nets, did not fish the entire vertical distribution of albacore. The depth of net from which the greatest commercial advantage could be realized cannot be ascertained from the above data since such factors as cost of netting, ease of retrieving, net storage area aboard the vessel, etc., must be considered. Without such considerations, a compromise between the gears used by Powell and POFI or 75 meshes would not seem unreasonable.

SUMMARY

If we consider our data comparable with that of Powell, the most productive net with which to fish albacore commercially in the central North Pacific would have a mesh size between $7\frac{1}{2}$ inches and $8\frac{1}{2}$ inches and a depth of 75 meshes.

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Reprinted from The Condor, Volume 61, May-June, 1959, Number 3, p. 226

Franklin Gull in the Central Pacific.—While on an oceanographic and tuna-fishing cruise to the Marquesas Islands in May and June of 1958, the author sighted a pair of Franklin Gulls (*Larus pipixcan*) at Taiohae Bay, Nuku Hiva. The birds were first seen on May 15 and remained in Taiohae Bay until May 25 when they disappeared. Both birds were black-headed, in typical nuptial plumage; the distinctive black markings across the white tips of the wings were clearly observed. In a search of the available literature on birds of the Marquesas, we failed to find any mention of the Franklin Gull.

Two representatives of this species were also sighted in Hawaiian waters at about the same time. On May 30, 1958, Henry Hasegawa collected a specimen of Franklin Gull about 2 miles off Kekaha Light, Kauai. The gull was in company with a flock of terns and shearwaters which were working over a school of skipjack tuna. The author examined the specimen after it had been mounted by a local taxidermist and compared it with the figures and description provided by Dwight (Bull. Amer. Mus. Nat. Hist., 52, 1925). This bird was also in typical breeding plumage and even in the preserved state showed a slight rosy "bloom" on the breast. This coloration was reported to be considerably more prominent on the freshly collected specimen. On June 14, Mr. Hasegawa saw a second Franklin Gull in West Loch of Pearl Harbor, Oahu; this bird was not collected, however.

Mr. Hasegawa is an engineer on a tuna fishing vessel and is thoroughly familiar with the common sea birds of the Hawaiian area. He collected the gull because he had never seen a bird of this type before in Hawaii and realized that its presence here was worth verifying.

The only other recent sighting of a Franklin Gull in Hawaii was that by John W. Slipp who saw and photographed a single specimen near Barber's Point, Oahu, on May 16, 1953 (Elepaio 14(1), 1953:7). The A.O.U. Check-list (1957:227) indicates that the Franklin Gull is "Accidental in Hawaii (Maui), ..." This statement was probably based on W. A. Bryan's list of Hawaiian birds in the St. Louis College collection (Auk, 18, 1901:382–387) which describes a specimen in immature plumage, most likely taken on Maui but with collection data lacking. The author has been an observer of Hawaiian birdlife for nine years but has not sighted the species in Hawaii in that period.—Joseph E. King, *Honolulu, Hawaii, November 20, 1958.*

Reprinted from the book MODERN FISHING GEAR OF THE WORLD, published April, 1959, pages 430-432

A NEW METHOD OF HANDLING LONGLINE GEAR A DESCRIPTION OF POFI "TUB" GEAR

by

HERBERT J. MANN

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bstract

Modifications to Japanese-type longline gear, by the introduction of a large, rotating tub from which the line is handled, have sulted in a considerable saving in manpower. Conventional gear can be operated in this manner with few changes. Instead of using di vidual baskets of line which must be separated and joined together for each day's fishing, a continuous mainline is set from, and hauled to, a wooden storage drum. This innovation is the product of continuing studies to increase the efficiency of longline gear.

Une nouvelle méthode de manipulation des palangres Description de la baille à lignes POFI

ésumé

On a obtenu une importante économie de main-d'oeuvre grâce à des modifications apportées aux palangres japonaises par l'intro- uction d'une grande baille tournante dans laquelle se trouvent les lignes. L'engin habituel peut être manoeuvré de cette façon avec peu de angements. Au lieu d'utiliser des paniers individuels de lignes qui doivent être désassemblées et réassemblées chaqué jour pour la pêche, on et à l'eau et on récupère dans une baille de bois une ligne principale continue. Cette innovation est le résultat de recherches en cours pour gmenter le rendement des palangres.

Nuevo método para manipular palangres. Descripción del "tambor" POFI para enrrollar palangres

xtracto

Las modificaciones introducidas a los palagres de tipo japonés mediante el uso de un "tambor" rotatorio desde el cual se manipula te aparejo de pesca economiza bastante mano de obra; además permite usar unidades de tipo convencional con sólo pequeñas modificaciones. n lugar del empleo de varias cuerdas madres que es necesario unir y separar en cada salida, se procede a calar y a levantar una sola alma- nada en el "tambor" de madera. Esta innovación es el producto de continuos estudios para aumentar la eficacia de los palangres.

THE Pacific Oceanic Fishery Investigations (POFI) of the U.S. Fish and Wildlife Service has found longlining to be an effective means of catching nas in the relatively baitless waters of the central cific. This report describes a new method of fishing ngline gear recently developed at POFI following a ggestion by Mr. A. K. Akana Jr., POFI fleet supervisor. The longline gear previously used by POFI was copied om conventional Japanese designs and, although equate as a sampling tool for exploratory fishing, it quired too many men, by American standards, to be ea: for commercial use. The so-called "tub" gear scribed below is the most successful effort to date to prove the efficiency of gear in this respect, in that it rrnits a material reduction in the manpower required operate longline gear.

The essence of the tub method lies in a novel means handling the mainline. Instead of the individual skets of conventional gear, which must be separated d joined together for each day's fishing, tub gear s a mainline of one continuous length which is shot m and hauled into, a large wooden storage drum or ub". Branchlines and floatlines are removed from the mainline as they come aboard and are reattached during shooting operations.

The tub method requires only minor changes in the design of conventional longline gear. Standard POFI gear, or any longline with detachable branchlines and floatlines, may be used by adding "D" rings (described below) to the mainline.

DESCRIPTION OF THE GEAR

The gear is of a flexible design so that it can be altered readily to meet the changing requirements of an exploratory fishing programme. Components are detachable and can be assembled so as to fish varying numbers of hooks at different depths.

Shown in fig. 1 is a schematic representation of a single unit, or basket, of POFI gear of the latest type. Sixty to a hundred such baskets are joined together to make a fishing set.

Mainline

The mainline of each unit is made up of fourteen identical sections knotted together by double sheet bends. Each

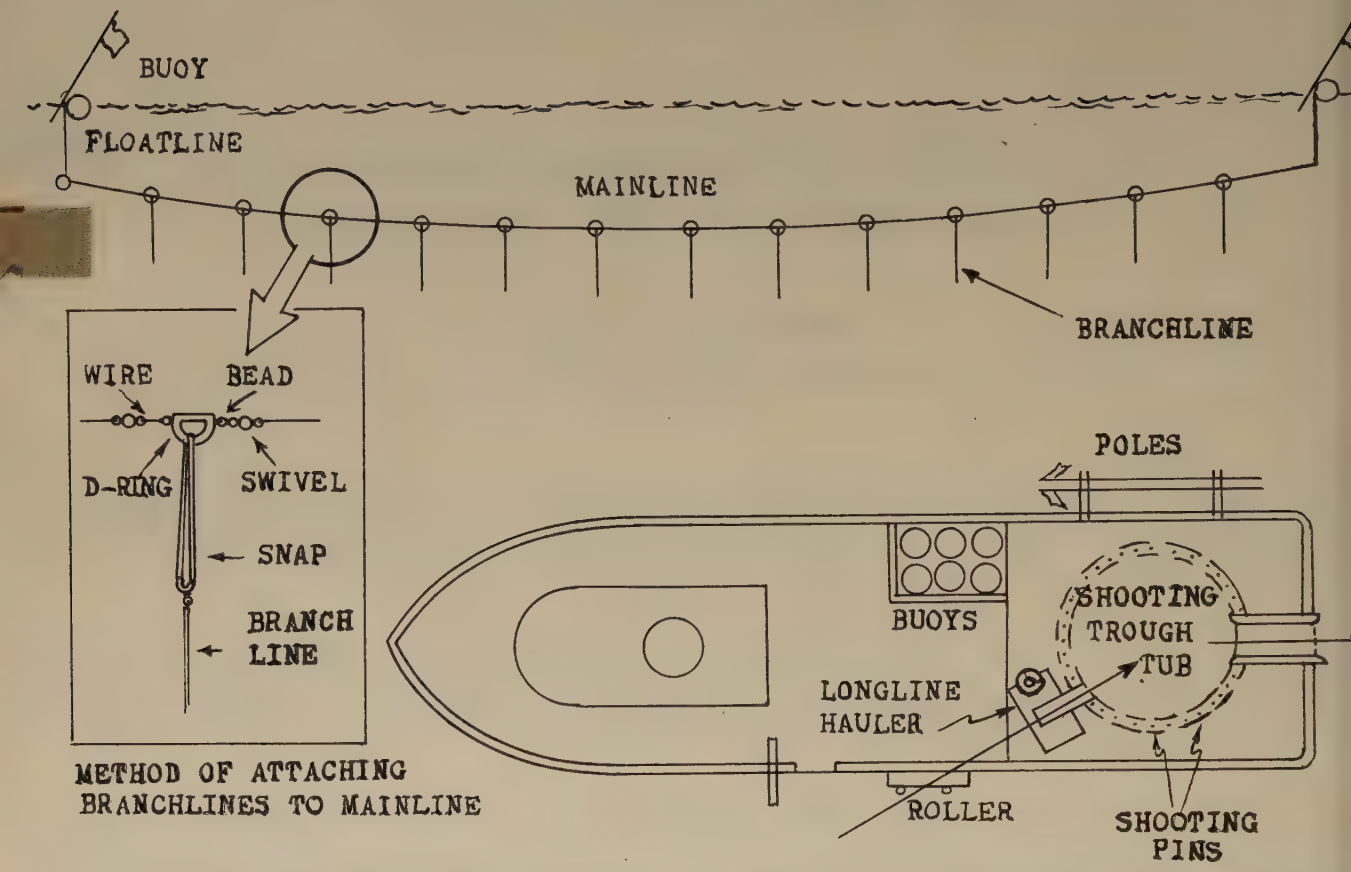

Fig. 1. Schematic drawing showing the arrangement of a single unit, or "basket", of POFI longline gear, and the location of the line storage tub on the stern of the vessel.

section consists of a 15 fm. length of preserved 261 thread hard-laid cotton twine with an eye splice in one end and a wire bridle with swivels, "D" ring, and pigtail at the other. Baskets are joined by a clover-leaf knot which is formed with an extra loop for attachment of the floatline.

Attachment of branchlines

The branchlines are attached to the mainline by the "AK" snap and "D" ring arrangement shown in fig.1. The "D" ring eliminates a troublesome defect of old gear. Formerly, "AK" snaps were clipped directly to a wire bridle. This type of attachment permitted the branchline to swivel around the mainline and prevented tangles when gear was being hauled aboard ship. But sometimes it failed to function properly when large fish pulled the branchline parallel to the mainline. At acute angles of pull, the snap ceased to have any swivelling action and sometimes was pulled out of shape or broken. The "D" ring maintains proper swivelling action. Rings are fabricated from stainless steel tubing with a lower section formed in a U shape and welded to the upper, straight tube section through which the bridle is rove. The wire bridles are made of a 6 in. length of 3/32 in. diameter 7×7 stainless steel wire rope with swivels connected to each end by means of Nicopress fittings. These fittings consist of malleable copper sleeves which are pressed on the wire by a ha tool. Brass beads threaded on the wire on both sid of the "D" ring act as miniature thrust bearings, a aid the swivelling action of the "D" ring. The bra swivels relieve torque on the mainline which occu when the line is being brought in by the hauler.

Branchlines, snoods and hooks

The branchlines are made of 2 fm. lengths of 261 thre line. An "AK" snap is spliced into the upper en The lower end terminates in an eye splice for securi snood and hook. The snoods are fashioned of 6 lengths of ·066 in. diameter 7 strand galvanised wi The upper end of the snood is fitted with a section $\frac{3}{8}$ in. rubber tubing which serves as chafing gear. T hooks, 8/0 or 9/0 tinned, are of a special shape w bent shank which allows them to hang in line w the snood.

Floatlines

Floatlines are made from 10 fm. lengths of 261 thre line. The lower end of each line has an "AK" snap f attachment to the mainline. Snaps are clipped to loo in the line, rather than to "D" rings, since it has be found that "D" rings and wire bridles do not hold under the incessant jerking caused by the rise and f of floats with sea and swell.

orage tub

own in fig. 1 is a schematic drawing of the wooden b used for storage of the mainline. The experimental odel used aboard the Fish and Wildlife vessel, "John . Manning", is a double-walled plywood cylinder easuring 12 ft. in diameter and 4 ft. in depth. The pacity is sufficient for the storage of 100 baskets of ar. For greater ease in shooting the tub is mounted ar the stern of the vessel, but adequate space between b and railing is left all around. The drum is supported the centre by a heavy bearing bolted to the deck; e outer edge runs on cast iron rollers of the type used support the turntable of a purse seining vessel. einforcing bands of 3 in. strap metal are welded around e outside of the tub for extra support, and 33 stainless eel shooting pins are spaced at equal intervals inside the b.

The gear is hauled by means of a longline winch of nventional Japanese design. Electrically powered by 3 h.p. motor, the winch brings the line in at a maximum te of about 1,000 ft./min. and coils it down automatic- y with only slight assistance from the winch operator. ne hauler is mounted so that the line is thrown just er the edge of the tub.

The shooting trough, similar in design to that used the Northwest Pacific halibut fishery, is a demountable eet metal form used to guide the outgoing mainline ring shooting.

PERATION OF THE GEAR

eparation

fore sailing, baskets of mainline are joined together d fed through the Japanese line hauler into the tub. o attempt is made to coil the line down uniformly o regular piles, but it is deflected by hand so that it evenly distributed in thickness over the bottom of e tub. As the "D" rings pass through the hauler, ey are caught and threaded upon the shooting pin arest the hauler. All fourteen rings of one basket e placed on the same pin and the knot marking the d of the basket is looped on top. The tub is then ned by hand until the next shooting pin comes in e with the winch. To avoid piling up the line, the skets are spaced on every other pin; when the tub s completed one revolution, a second and finally a rd layer of line is laid over the first so that 99 baskets held on 33 shooting pins. The tub is covered with anvas tarpaulin to prevent the line from being dis- ced in rough weather.

ooting

en shooting the tub is rotated by hand until the ermost basket comes under the shooting trough. e vessel is steered on a steady course at a speed of up 9 knots. The buoy and floatline, marking the end of set, are attached to the mainline, which in turn is through the trough, and the assembly is thrown rboard. Thereafter the drag of the gear pulls the nline overboard as the vessel proceeds.

Hooks are baited with sardines, *Sardinops caerulea* (Girard), or herring *Clupea pallasii* (Valenciennes). Individual branchlines are attached to the mainline by clipping the "AK" snap at the upper end of the branchline to the uppermost "D" ring. They are then laid in the shooting trough one by one with the hook and bait dangling overboard. Floatlines are attached in the same manner. As the end of each basket leaves the shooting pin, the tub is turned to keep successive baskets in line with the shooting trough.

Hauling

The gear is hauled through side rollers on the starboard side of the vessel. The mainline is led through the hauler and coiled into the tub. As branchlines come aboard, the winch is stopped momentarily and the "AK" snaps are removed from the "D" rings. The branchlines are coiled in specially built plywood boxes and are stowed with hooks exposed on one side and with the "AK" snaps held by clips on the other. Fish are gaffed and brought aboard through an opening in the bulwark. The line is stowed in the tub as described before, with three baskets of "D" rings being placed upon each pin.

Broken or tangled portions of mainline are removed by unknotting the line section junctions, repaired, and joined to the end of the mainline when fishing finishes. Because the sections are identical they need not be restored to their original positions.

CONCLUSIONS

Tub longlining, in particular, seems applicable to small vessels carrying a limited number of men.

The saving in labour is considerable. Since a basket of POFI gear weighs about 40 lb. when wet and a day's set may consist of up to 100 baskets, about 4,000 lb. of wet line would have to be cleared out and restowed by hand for each day's fishing, when using conventional methods. The POFI tub method eliminates all man-handling by flaking the line directly into the tub.

Five men were found sufficient to operate the gear, as against a crew of 11 men required for conventional gear. Both methods require, for each basket of line, about 1½ min. for shooting and 3½ min. for hauling.

Some difficulties in operation have been experienced, the most troublesome being excessive wear and tear on the mainline, due to the "D" rings running at high speed through the overside rollers and longline hauler. At high hauling speeds, "D" rings strike the rollers or hauler with enough force to bend the rings or break wire bridles. Much needed is a method of joining branchlines to the mainline by a system which permits swivelling freely in any direction but which offers little resistance to passage through the line hauler.

One difficulty anticipated, which failed to materialize, was fouling of the mainline during shooting operations. Provided that the shooting trough is properly designed, the outgoing mainline runs smoothly in it and fouling is less than when shooting by conventional methods.

All POFI tubs are rotated manually. Mechanical rotation has not yet been installed but, if used commercially, powered tubs should increase efficiency.

Fishing News (Books) Ltd., 110 Fleet Street, London, E.C.4, and printed by Merritt & Hatcher Ltd.,

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Reprinted from Limnology and Oceanography
Vol. IV, No. 1, January, 1959
Printed in U.S.A.

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Effect of Water Clarity on Albacore Catches

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Effect of Water Clarity on Albacore Catches

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ABSTRACT

The numbers of albacore (*Germo alalunga*) taken by gill-netting and surface trolling are seriously affected by the transparency of the water. Observations assembled from a fishing cruise between Hawaii and the Aleutians in 1956 and from a cruise off the Pacific coast of North America in 1957 showed that the efficiency of the troll was greater in clear water than in more turbid water. Very likely this increase in efficiency is a power function of the change in transparency. Though the data are not so convincing, the results suggested that the gill net fishes more efficiently in turbid water. The ratio of troll catch to gill-net catch bears the following relation to a reciprocal function of the extinction coefficient—

$$\frac{\text{Troll} \times 100}{\text{Gill net}} = .0000394 \left(\frac{1.7}{\text{Extinction coefficient}} \right)^{4.55}$$

Since the theoretical maximum power function of the troll catches alone is about 3, the residual of 1.55 may be associated with the reverse effect that water clarity has on the efficiency of the gill net.

These data are discussed in relation to evaluating the abundance of any species of fish when the method of assessment involves visual responses. In addition, the possibility is discussed that water clarity may be an important ecological factor in the ocean in that the efficiency of sight feeders will be reduced as turbidity increases.

INTRODUCTION

Students of the ocean have long recognized that water clarity is an important ecological variable through its effect on photosynthesis (Clarke 1939) and on the maximum depth at which organisms might be able to see (Clarke 1936). Tamura (1957) and other investigators have concerned themselves with the morphology and histology of fish eyes and with measurements of the thresholds of vision in terms of illumination and of the most efficient level of illumination for vision (Tamura *et al.* 1957). Finally, in recent years there has been considerable attention devoted to variation in the optical properties of ocean water with depth (Jerlov 1951). Our concern is with a slightly different aspect of the problem. We wish to consider how far a fish can see in its normal habitat (a quantity similar to visual range as defined by Jenkins and Bowen 1946), and its effect on distribution and sampling of the fish.

In 1955 the writer hypothesized that the clarity of oceanic waters may have a direct influence on the abundance and distribution of tunas through its effect on their ability to forage. The hypothesis seemed to have merit, and observations and preliminary investigations pertinent to the problem were initiated shortly thereafter. A study of the morphology and histology of tuna eyes was begun under contract at the University of Hawaii, and we began measuring water clarity in connection with fishing surveys insofar as instrumentation and time permitted.

The material to be presented here does not permit direct discussion of the primary hypothesis. Rather, it shows that methods of catching tuna that depend on visual response of the fish are efficient in proportion to the clarity of the waters—by implication supporting the original hypothesis. The evidence shows that trolling, which depends on a positive visual response, is most efficient in clear water, whereas gill-netting, which is dependent on non-response, is most efficient in turbid water.

MATERIALS AND METHODS

The data utilized in this study were collected during the course of two albacore

(*Germo alalunga*) fishing surveys. The first survey was conducted in the summer of 1956 in temperate waters lying between Hawaii and the Aleutian Islands. The second survey was made during the summer of 1957 in the waters off the west coast of the United States. For the purposes of this study pertinent observations were grouped into synthetic stations. These are centered on overnight gill-net sets, and also include trolling during the afternoon preceding and the morning following the gill-net sets. Daylight extinction measurements were made near mid-day before and after the gill-net sets.

Daylight extinction was measured by determining the depth at which 5 per cent and 10 per cent of the surface illumination persisted. The apparatus consisted of a deck cell, mounted on gimbals and containing a Weston Photronic Model 856 type 1 photoelectric cell, and a similar submerged cell, each equipped with a suitable filter to match its response to the standard luminosity curve adopted by the International Commission on Illumination. A microammeter completed the apparatus. Determinations were made by placing an appropriate calibrated cover over the deck cell and lowering the sea cell until its current output equalled that of the deck cell. The two determinations (5 and 10 per cent) were coverted to extinction coefficients (Sverdrup *et al.* 1942, p. 82), and the two extinction coefficients were averaged. As might be expected from the differential extinction of different wave lengths of light through a water column and the possibility of heterogeneity of the water columns, the two coefficients (5 and 10 per cent) were not identical, but they generally bore a linear relation to one another and to the average of the two, suggesting that the average coefficient is a useful relative measure of transparency.

A final problem with respect to the extinction coefficients was to derive a value for each synthetic station that would be representative of clarity during trolling and gill-netting. Since ordinarily the ship moved 10–60 miles from one noon to the other, that is, from one light measurement to the next, there were no transparency observations directly associated with the gill-netting. Though somewhat unsatisfactory, our method of solving the difficulty was to average the two noon values of clarity bracketing the fishing, on the assumption that transparency varied linearly between stations. The light penetration measurements when plotted on surface charts to check this assumption indicated that, by and large, transparency varied in a progressive manner over a noon-to-noon vessel track. In three instances additional values obtained two or three days before or after a synthetic station were included because they fell on the vessel track. Thus each extinction coefficient employed here usually is the mean of four field determinations: two (5 and 10 per cent) at the noon preceding the fishing effort; and two (5 and 10 per cent) at the noon immediately following the fishing effort. It should be noted that the most turbid water encountered corresponded roughly to the oceanic maximum recognized by Sverdrup *et al.* (1942, p. 85) and that none would fall in the category of coastal water with respect to turbidity.

Trolling was generally carried out with the vessel proceeding at 5–7 knots, trailing 5 or 6 lines. These lines bore a variety of "albacore lures," and there was no indication from the catch that one lure was superior to the others. No adjustments were made in the raw troll catches except for one station during which there was no trolling on the morning following the gill-net station. In that instance the troll catch of the afternoon preceding the gill-net station was arbitrarily doubled.

The albacore gill nets were made up of shackles about 300 feet long and 30 feet deep, with mesh size ranging from 4½ to 7½ inches (stretched measure). Between 9 and 18 shackles were fished at each station, 12 being the typical number. Since all mesh sizes took albacore, we have made no attempt to adjust the catch for varying proportions of the different mesh sizes. Rather, the results are expressed in terms of catch per 12 shackles of net. Gill nets were set at dusk and hauled just prior to dawn.

Approximately 35 sets of fish-catch and transparency measurements were available

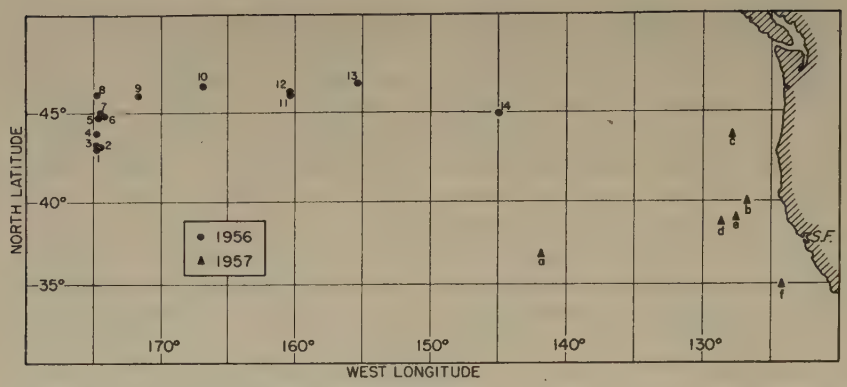

FIG. 1. Northeastern Pacific Ocean, showing the locations of troll and gill-net stations used in this study. The July-August 1956 cruise is represented by solid circles and the June-August 1957 cruise by triangles.

TABLE 1. *Albacore catches and mean extinction coefficients during 1956 and 1957*

Dates and positions refer to the start of the gill-net stations. Gill-net catches are adjusted to 12 shackles. Troll catches are from noon to noon bracketing the gill-net stations. Extinction coefficients are the means of the 10 and 5 per cent determinations of all light stations during the noon-to-noon periods.

Station	Date	Latitude	Longitude	Gill-net catch	Troll catch	Extinction coefficient
1	7–25–56	43° 02′ N	174° 57′ W	27	5	.119
2	7–26–56	43° 07′ N	174° 52′ W	81	1	.137
3	7–27–56	43° 10′ N	174° 53′ W	33	1	.148
4	7–28–56	43° 56′ N	174° 57′ W	16	1	.157
5	7–31–56	44° 48′ N	174° 46′ W	112	11	.086
6	8–1–56	44° 54′ N	174° 08′ W	32	11	.090
7	8–2–56	44° 58′ N	174° 29′ W	33	6	.094
8	8–3–56	46° 01′ N	174° 58′ W	16	0	.089
9	8–16–56	45° 57′ N	171° 44′ W	53	4	.095
10	8–19–56	46° 28′ N	166° 54′ W	33	3	.130
11	8–21–56	46° 00′ N	160° 16′ W	63	0	.130
12	8–22–56	46° 03′ N	160° 16′ W	79	0	.149
13	8–26–56	46° 25′ N	155° 15′ W	13	0	.116
14	9–1–56	44° 57′ N	145° 01′ W	4	7	.106
a	6–19–57	36° 53′ N	141° 41′ W	27	4	.052
b	7–9–57	39° 59′ N	126° 51′ W	3	12	.063
c	7–23–57	43° 42′ N	127° 53′ W	11	12	.072
d	7–28–57	38° 45′ N	128° 37′ W	2	15	.055
e	7–29–57	39° 00′ N	127° 31′ W	28	6	.074
f	8–9–57	34° 50′ N	124° 10′ W	2	13	.071

for study. These were reduced to 20 by considering only those stations in which the aggregate catch of the gill-net set and the trolling was 10 or more fish. This limitation reduced the variability in the data and, perhaps even more important, restricted the study to waters in which albacore were present in fair numbers. Thus, the problem of the general distribution of albacore and the possible interaction of other environmental factors on the catches, such as temperature, is minimized. The locations of the 20 stations that met the above criterion are shown in Figure 1 and the data are tabulated in Table 1.

RESULTS

The results of gill-netting show little numerical relation to the troll catches (Fig. 2). Though far below the level of statistical significance, the two have a negative correlation coefficient as would be expected if they are affected in opposite ways by water clarity. Statistically significant results should not be expected, however, without enormous amounts of data, because the treatment does not overcome variations in the absolute abundance of albacore from station to station; and since two measures of abundance are plotted, this effect is doubled.

Troll catches, plotted as a function of water clarity (extinction coefficient), show a negative relation ($r = -0.738$, $P < 0.01$) (Fig. 3). A linear function was applied, not because it is proposed that the two variables bear a linear relation to each other, but rather as a simple way to show that there is an association between them. Again, an unknown source of variability in this treatment must be the changes in the true abundance of albacore from station to station. However, the effect of this source of variability is less than in the previous analy-

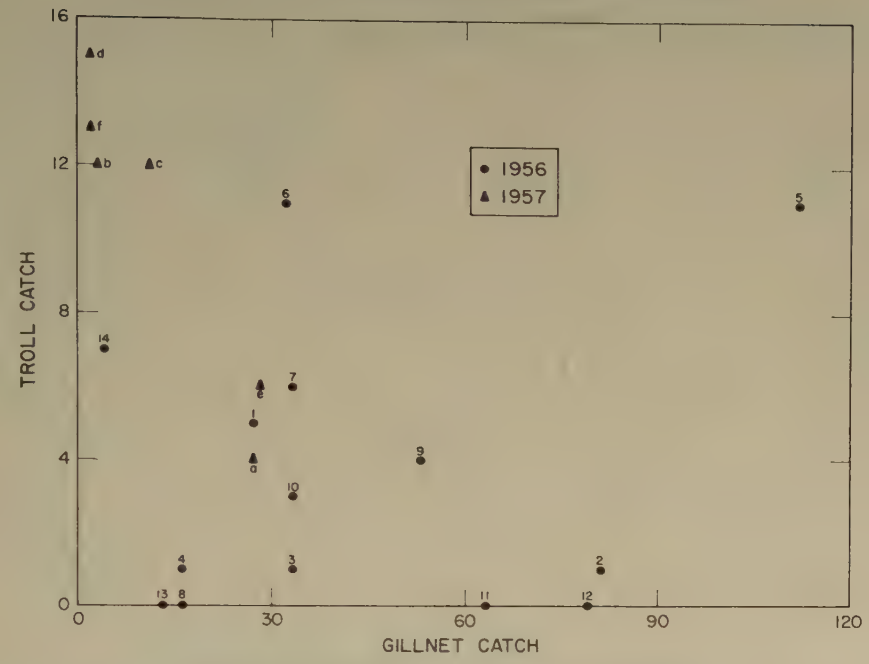

FIG. 2. Troll catch of albacore, plotted against the gill-net catch.

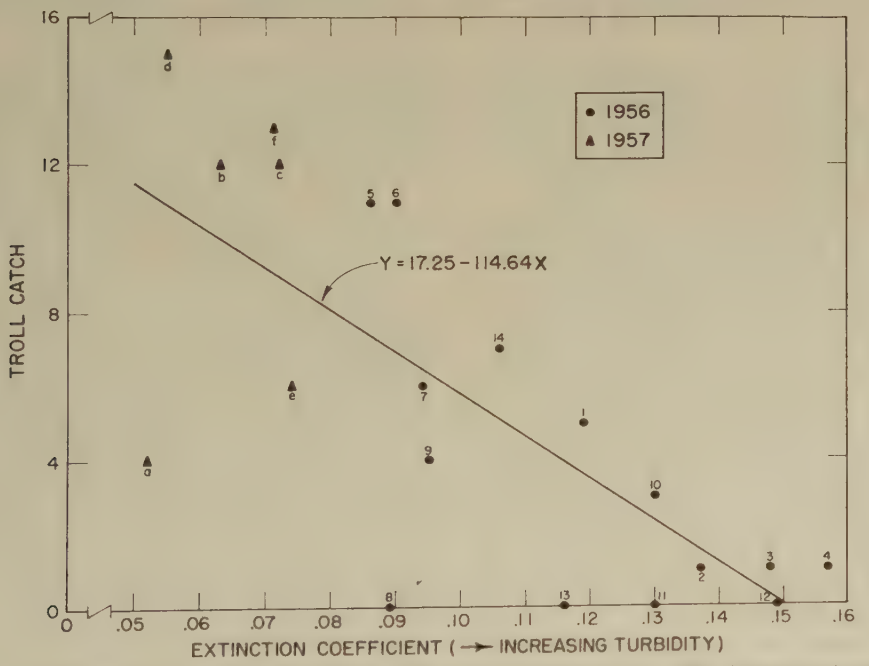

FIG. 3. Albacore troll catches plotted against water transparency. The larger extinction coefficients represent less transparent water.

sis because we consider only one measurement of the albacore population. Figure 3 could, of course, be interpreted to mean that albacore are most abundant in clear water or that trolling is most effective in clear water or, as a third possibility, there may be an interaction or systematic effect of the different variables.

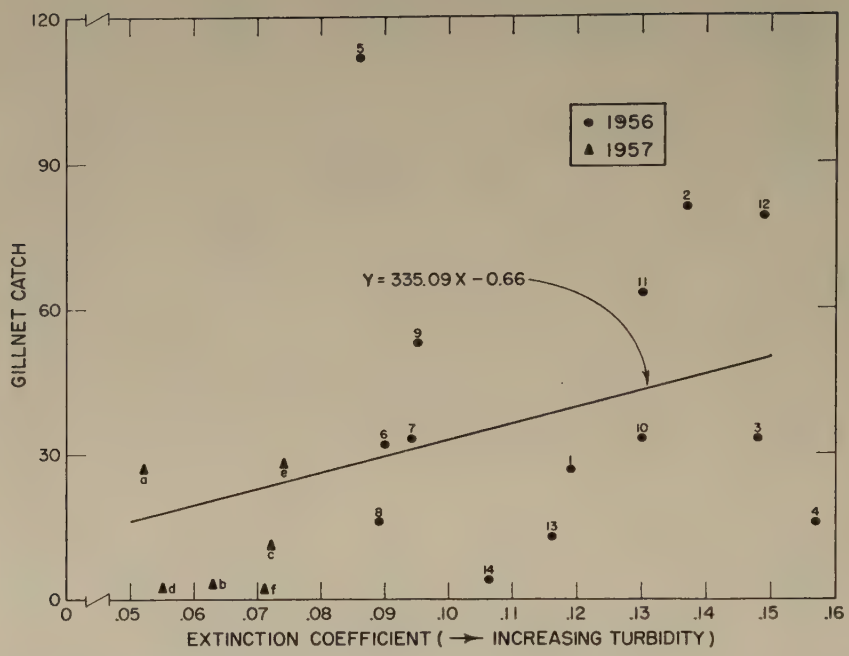

FIG. 4. Albacore gill-net catches plotted against water transparency. The larger extinction coefficients represent less transparent water.

Gill-net catches plotted against turbidity show a positive relation ($r = 0.36$, $P > 0.05$) (Fig. 4). Lack of statistical significance may well stem from the ever-present variability associated with differences in the actual density of the albacore population and the tendency for night gill-netting to reduce or perhaps even eliminate the effect of variations in water clarity. Auxiliary sources of light must also be considered with respect to the gill net. Extremely clear water is generally low in biomass and probably would produce little bioluminescence in the vicinity of the drifting gill net. Turbid water in the marine environment is generally high in biomass and might therefore result in high bioluminescence. This additional variable would operate to reduce the slope of the regression.

If we accept the slope in Figure 4, we are again offered three alternate conclusions: (1) that albacore are more abundant in more turbid water, (2) that the gill net fishes more efficiently in more turbid water, or (3) that there is systematic interaction among the variables. These are opposite to the conclusions drawn from the troll catches. If the slope, which falls slightly short of significance, is rejected in compliance with the usual statistical standards, we can conclude that the magnitude of the gill-net catch and presumably the density of the albacore population is independent of water clarity.

The preceding analyses of water clarity and albacore catches were handicapped by inability to estimate or control variations in absolute abundance from station to station. One way to eliminate the effect of absolute abundance is to express the catches as a ratio (Troll catch ÷ Gill-net catch), adding "1" to the three zero catches in Table 1. If these ratios are plotted against water clarity, the slope obtained will be independent of abundance and should only reflect the relative efficiency of the two sampling methods with respect to water clarity. This treatment has the disadvantage of introducing into one analysis all sources of random variability, that is, variability in gill-net catches, troll catches, and random errors in assessing water clarity.

In this final analysis an approximation of

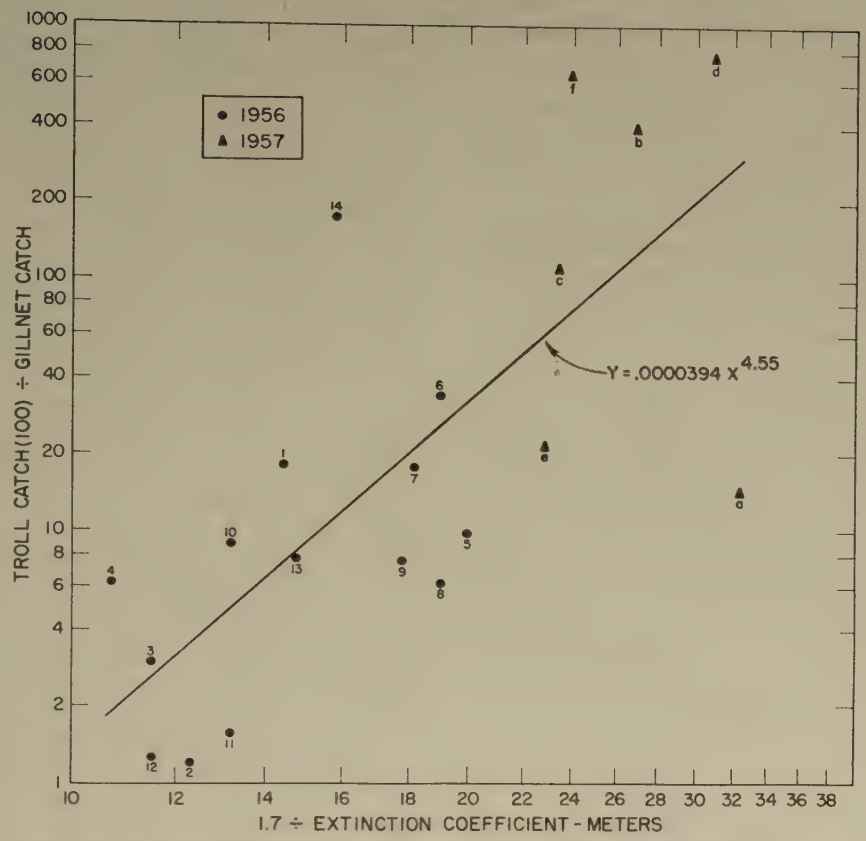

FIG. 5. The ratio of troll to gill-net catches plotted as a function of the reciprocal of the extinction coefficient.

the distance an albacore can see (visual range), *i.e.*, $\frac{1.7}{K}$ is employed as the measure of water clarity instead of the extinction coefficient (K). This reciprocal quantity of the extinction coefficient was found by Poole and Atkins (1929) to be equal to the vertical depth at which a Secchi disk could be seen in the English Channel. A comparison of our Secchi disk measurements and the computed $\frac{1.7}{K}$ indicates the latter is also a good approximation in these waters. (The observed Secchi disk measurements were not used in the present study because they lack the precision of the photoelectric determinations, principally because of variation in boundary conditions at the sea surface.)

The relative efficiency of the two sampling methods $\left(\frac{\text{Troll} \times 100}{\text{Gill net}}\right)$ is treated as a power function of the visual range $\left(\frac{1.7}{K}\right)$ because the efficiency of the troll should be related to some power of the radius of vision, that is, the visual range. Thus the following type of equation should obtain—

$$\frac{\text{Troll} \times 100}{\text{Gill net}} = a\left(\frac{1.7}{K}\right)^b$$

The empirical solution to the above equation (Fig. 5) gives a value of 3.95×10^{-5} for a and 4.55 for b. The slope is highly significant ($P < 0.001$) as is the associated correlation ($r = 0.772$). Again, as suggested by the other treatments, the efficiency of the troll in respect to the gill net is apparently a function of water clarity. This analysis tends to implicate the gill net as well as the troll, because the b value (4.55) is higher than might be expected if the gill net is unbiased with respect to water clarity. That is, if an instantaneous function is con-

sidered, the volume of water in which the troll lure is visible to albacore should be close to a cube function of the visual range because an object near the surface is visible to all fish in a "hemisphere," with locus at the object and a radius equal to the visual range.[1] No significantly higher exponent can be theorized, so most of the residual (1.55) must be either related to increasing gill-net efficiency with increasing turbidity or to sampling error or both.

DISCUSSION

The validity of using extinction coefficients (K) to estimate how far a fish can see is not clearly established. Poole and Atkins (1929) showed that in the English Channel $\frac{1.7}{K}$ was a linear function of the vertical limit of Secchi disk visibility. The present problem, however, involves vision at all angles from the horizontal to the vertical. We have made measurements comparing vertical and horizontal Secchi disk visibility at two locations in Hawaiian waters with the observer on a submerged platform about 4 feet below the sea surface. In each of two pairs of observations, one determination was made vertically and a second, with a similar target, horizontally, the target being suspended from a buoy about 10 feet below the surface. In each instance the vertical and horizontal determinations were nearly identical, varying about 10 feet (vertical distances 150 and 180 feet). Thus the vertical Secchi disk determinations appear to provide a fairly close approximation of horizontal visual range. Since this quantity is a function of the extinction coefficient it appears that the use of $\frac{1.7}{K}$ as a first approximation of visual range is justified. The basic reason for the validity of this approximation lies in fact that loss of contrast through scattering is the most important element in fixing "visual range" in the open ocean, with absolute level of initial illumination of minor importance (Duntley 1952).

Perhaps it is redundant to point out that the evidence given questions the validity of estimates of tuna abundance if the methods are such that the fish can employ vision in a positive or negative sense in relation to the gear. A case in point are Figures 3, 4, and 5 in which the data for 1957, while not incompatible with those obtained in 1956, are not randomly distributed with respect to the 1956 results. This apparently resulted because gill-net stations in 1957 were deliberately located in areas where trolling was "good," practically precluding a random distribution of gill-net catches with respect to water clarity. Comprehensive sampling programs employing two or more types of gear might help to overcome this problem, and more precise information on the magnitude of the effect of water clarity and other environmental factors on the efficiency of the sampling method might permit adjustment of catches to obtain a more reliable measure of actual abundance. Another alternative is to sample by means of measures not dependent on any reaction of the fish to visual stimuli. For instance, the gill net as used for albacore appears to be an improvement over the troll, though the gill net might be more susceptible to other factors such as the vertical distribution of fish and the thermal structure of the water. An ecologist attempting to relate abundance of, say, albacore to other factors in the environment might even better be served by the uncertain but unbiased estimates of fish abundance that might be obtained by echo sounders.

Though it is not possible to treat the subject with any precision, it is worthwhile to consider further the possible effect of water clarity on the absolute abundance of albacore and other sight feeders. The first problem, of course, is to establish that they are sight feeders. This is indicated with respect to

[1] The cube function is only an approximation because an object can be seen over the greatest range from directly below, and at a lesser distance from a horizontal direction (Duntley 1952). Thus the volume of water in which the lure is visible is an ellipsoidal solid with a vertical axis slightly greater than the horizontal. The present data do not permit precise resolution of the parameters involved, but trial computations show that no more than 0.2 of the 1.55 can be ascribed to deviations from a sphere.

albacore and other tunas by general observations on their behavior at sea and by such objective data as failure to make captures at night by trolling. It is also suggested by their large and presumably efficient eyes and by their ability to swim rapidly. Vision in the open ocean appears to be related to turbidity, which is of course related to the amount of particulate matter in the water. In the open ocean the amount of particulate matter is at least in part a function of the biomass; thus as the standing crop of food increases, the relative ability of the tunas to locate and capture a prey animal must decrease. Fish such as tuna might then be at a loss in an environment judged ideal on the basis of the standing crop of organisms. An extreme case of this effect might run as follows: A particular area contains a crop of tuna forage sufficient to support a particular density of tuna. An increase in the rate of replenishment of nutrients in that area through upwelling or some other phenomenon causes an upsurge of phytoplankton, thus decreasing the visibility. However, there might not yet be an increase in the tuna food supply so the tunas would be forced temporarily to desert this particular area. Perhaps this effect contributes to the reported exclusion of herring from dense populations of phytoplankton, for they also appear to employ vision in capturing food (Vilter 1950).

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U. S. DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
SEP. NO. 534

January 1959 Washington 25, D.C. Vol. 21, No. 1

A SURVEY OF THE AMERICAN AND JAPANESE ALBACORE TUNA FISHERIES IN THE PACIFIC THROUGH EXAMINATION OF CATCH STATISTICS

By Tamio Otsu*

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ABSTRACT

Catch statistics of the American and Japanese albacore fisheries in the temperate and tropical Pacific Ocean are presented. There has been a fourfold increase in Pacific albacore landings since the prewar years. The Japanese account for about 75 percent of the landings.

Judging by catch statistics alone, the two Japanese North Pacific fisheries appear to be quite stable, even at the present high level of production. There is no indication of a declining resource. While the Japanese South Pacific fisheries are relatively recent in origin, and have not stood the test of time, the present status is encouraging. The American fishery has been beset with marked fluctuations in landings but there is no evidence that fishing has adversely affected the stock.

All indications on the present status of the albacore fisheries point to the parallel rise in effort and catch.

INTRODUCTION

The three major fisheries for albacore tuna, Germo alalunga (Bonnaterre), in the Pacific, all of which are located in the Temperate Zone of the North Pacific Ocean are: (1) the Japanese spring and summer live-bait fishery, (2) the United States west coast summer and fall fishery, and (3) the Japanese winter long-line fishery. In addition, the Japanese tuna long-liners catch much albacore in the tropical Pacific (see fig. 1).

Statistics from each of these fisheries are presented. Certain biological information is also examined for possible clues to the relationship of fish making up the stocks in the various fisheries. By examining the statistics, it is hoped that enough evidence can be gathered which will lead to a knowledge of the population structure of the Pacific albacore, and more important, to a definition of the present status of this important resource. For a population study, much more detailed statistics than are available would be required.

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This study as well as others pertaining to the albacore resources in the Pacific are being conducted by the Pacific Oceanic Fishery Investigations of the U. S. Bureau of Commercial Fisheries under Public Laws 329 (80th Congress) and 466 (Saltonstall-Kennedy Act, 83rd Congress).

MAJOR PACIFIC ALBACORE FISHERIES

JAPANESE SPRING AND SUMMER LIVE-BAIT FISHERY: A description of this fishery has been given by Van Campen[1/], and only a few of the more important points are repeated here. This fishery is conducted near Japan from late April to July, and is a part of the more extensive pole-and-line fishery for skipjack (Katsuwonus pelamis). Boats fishing for skipjack tuna, which appear in early spring off southern Japan, begin to fish for albacore which become available off central Honshu, Japan, about late April or early May. The surface schools of albacore follow the northward extension of the warm Kuroshio Current along the coast of Japan;

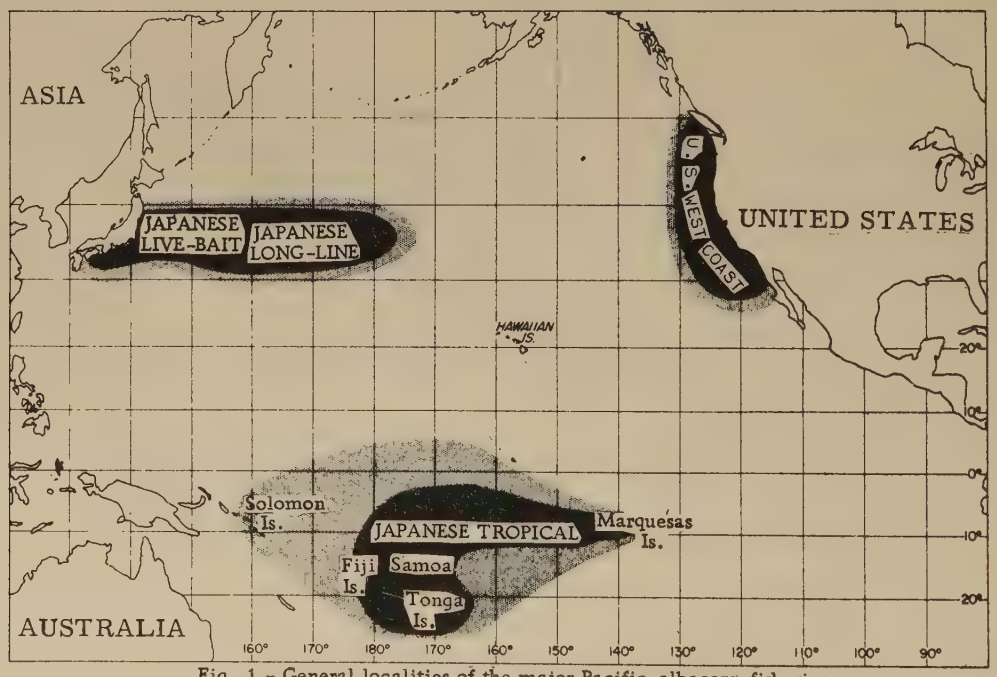

Fig. 1 - General localities of the major Pacific albacore fisheries.

their availability quickly reaches a peak in June, and then rapidly drops off as schools move farther offshore to the eastward. During July, the boats begin to return to skipjack fishing as the albacore go out of range or disperse and become harder to locate. Van Campen has pointed out that in recent years there was an eastward extension of the albacore grounds from about 155° E. to 165° E. longitude, and that this undoubtedly reflects the growing proportion of larger vessels in the fleet which are able to go farther offshore in pursuit of the fish.

UNITED STATES WEST COAST SUMMER AND FALL FISHERY: The albacore occurs along the Pacific Coast of North America from southern Baja California to Alaska between latitudes 25° and 59° N. (Clemens 1955). Since 1945 the majority of the fish have been caught in an area between Baja California and San Francisco within 400 miles of the coast, while between 1937 and 1945 large quantities were also taken off Oregon, Washington, and British Columbia. The year 1956 marked the return of the albacore to Pacific northwest waters after several years' virtual ab-

1/Van Campen, W. C. Manuscript. The Japanese Summer Albacore Fishery. Submitted for publication.

sence. Typically, the fishery begins in June off southern California, develops rapidly in July, reaches a peak in August and September, declines during October and November, and ends in December. Like the Japanese live-bait fishery, it is based on surface schools of albacore. The fish are taken by trolling and live-bait fishing. As the season progresses the fishery tends to move northward along the coast and also outward from the coast.

JAPANESE WINTER LONG-LINE FISHERY: This fishery is conducted between November and April over a broad area of the Temperate Zone of the North Pacific extending from the coast of Japan to the vicinity of 175° W. longitude generally between 30° and 40° N. latitude (Nakamura 1951, Suda 1954). The fishing ground gradually shifts southward as the season progresses, being centered between about 34° and 40° N. in November, and between 26° and 32° N. in March. This southward movement ceases in March and there is a reversal in the movement of the fishery beginning in April. The winter long-line fishery is terminated in April, and the live-bait fishery begins soon after.

The description of this fishery as well as that of the live-bait fishery are overly simplified versions of a more complex picture. Van Campen[1/] pointed out that while Japanese writers often imply that all pole-and-line fishing is done in the spring and summer and all long-lining in winter, some albacore are taken by both methods in all months of the year.

OTHER JAPANESE FISHERIES FOR ALBACORE

Two relatively new fisheries, which yield significant amounts of albacore for the Japanese, are the mothership-type fishery and the so-called "foreign-based fishery," both of which exploit albacore along with other species of tunas in the tropical Pacific Ocean. Fishing is done by the long-line method. The mothership-type tuna operations began soon after World War II, while the fisheries based in foreign ports are of more recent origin.

MOTHERSHIP-TYPE FISHERY: The first large-scale commercial mothership-type tuna expedition in Japanese fisheries history was undertaken by the Taiyo Fishing Co., Ltd., in June 1950 following a directive issued by the Supreme Commander for the Allied Powers which permitted the Japanese to send expeditions to certain defined areas of the high seas adjacent to the Caroline, Marianas, and Marshall Islands. This expedition was composed of a 10,000-ton mothership and 25 long-line boats ("catchers"), which fished for a period of 2½ months. Details of this venture and several which followed, as well as the history of this type of operation in the Pacific, are presented by Shimada (1951), Ego and Otsu (1952), and Van Campen (1952). Such expeditions were authorized under the premise that fishing vessels operate only within a specified area, and under the rigid control and supervision of a mothership. That the Japanese found these large-scale ventures successful is attested to by the fact that they have been continued even after all restrictions on movements on the high seas were removed by the ratification of the Peace Treaty.

The announced plans for 1958 mothership operations involve three separate expeditions as follows: A 3,000-ton mothership and 23 catchers operating from May 20 through September 30, a 3,800-ton mothership and 35 catchers operating between May 10 and September 20, and an 11,000-ton mothership with 50 catchers operating in August and November.[2/] These operations are reported to be similar in scope to the 1957 operations.

FOREIGN-BASED FISHERIES: At the present time there are two fisheries operating out of foreign ports in the Pacific; one at Espiritu Santo, New Hebrides, and

1/See page 2.
2/Fisheries Economic News.

the other at Pago Pago, American Samoa. No statistics are available for the operation based in New Hebrides; an enterprise reportedly involving American, British, and Japanese capital. According to information available, the fishing base was completed in November 1957, and operations were under way in July 1958 with about eight Japanese tuna long-line boats.

The fishery in American Samoa, a joint enterprise between a large United States west coast cannery and certain Japanese fishing firms, began in 1954 (Van Campen 1954). Starting with a small fleet of 7 Japanese tuna boats, this operation has expanded considerably, and today the American Samoa cannery is being served by a fleet numbering more than 30 long-liners. Albacore, along with other tunas and spearfishes, are landed throughout the year. There is no clear seasonal variation in albacore landings but the more productive months appear to be from August through February.

ALBACORE LANDINGS IN THE UNITED STATES AND JAPAN

Annual United States west coast and Japanese albacore landings are presented in figure 2. These and other statistics given in this article are in short tons. The source data are those cited by Van Campen.[1]/ The Japanese landings include fish taken by the two major fisheries as well as lesser amounts landed by independently-

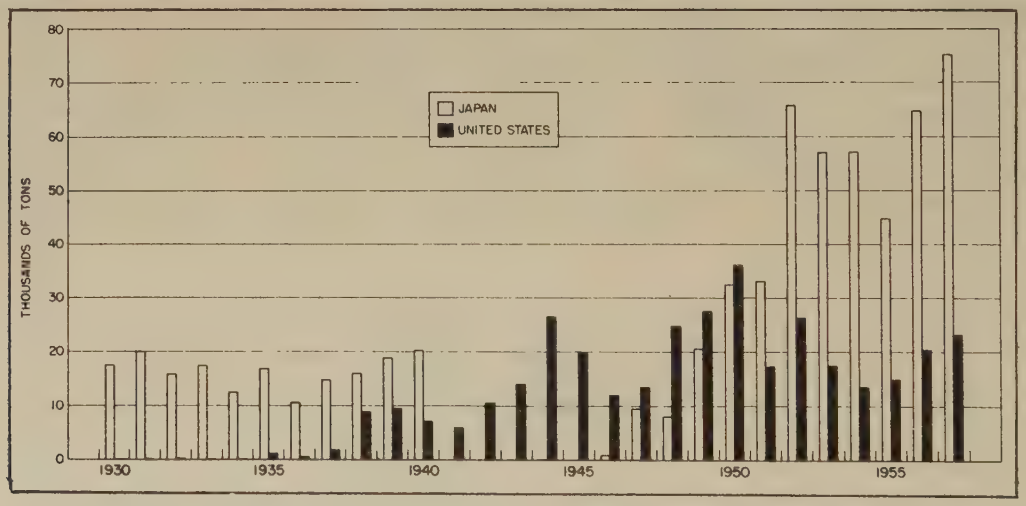

Fig. 2 - Japanese and United States west coast annual albacore landings, 1930-57.*

*The 1957 Japanese landings were obtained from statistics provided by the Nankai Regional Fisheries Research Laboratory, Japan.

operating tuna long-liners from tropical waters of the Pacific and Indian Oceans. The statistics do not permit segregation of Pacific and Indian Ocean albacore landings. However, since most of the albacore are taken in Pacific waters, it is probably of little consequence to ignore the distinction, and perhaps even consider the Indian Ocean as a further extension of the Pacific grounds. There are certain irreconcilable discrepancies. Judging from the landings shown in figure 2 and the annual landings of the two major fisheries shown in figure 4, it appears that Japanese landings accounted for by other than the two major fisheries are included in the figures of total Japanese landings only for certain years. The figures as given by Japanese sources are presented without any adjustments.

The United States landings of albacore were at an extremely low level during the early 1930's. Albacore providied the major portion of the tuna pack from the beginning of the industry in California in 1903 to the early 1920's. There were average landings of about 9,000 tons a year between 1916 and 1925--the years for which statistics are available. Following a record year in 1925 when about 11,000 tons

1/See page 2.

were landed, albacore suddenly failed to appear on the West Coast in its usual abundance. For the next 12 years the albacore catch was negligible in the United States. In waters off the Pacific Northwest, albacore showed up in commercial quantities for the first time in 1937, and a commercial pack was put up in Oregon and Washington in 1938 (Powell and Hildebrand 1950). This marked the beginning of a fishery in the Pacific Northwest which grew for several years and reached a peak in 1944 with landings of 17,000 tons. This fishery then declined until virtually no landings were made in 1952. In 1956 the albacore again returned in commercial quantities to waters off the Pacific Northwest.

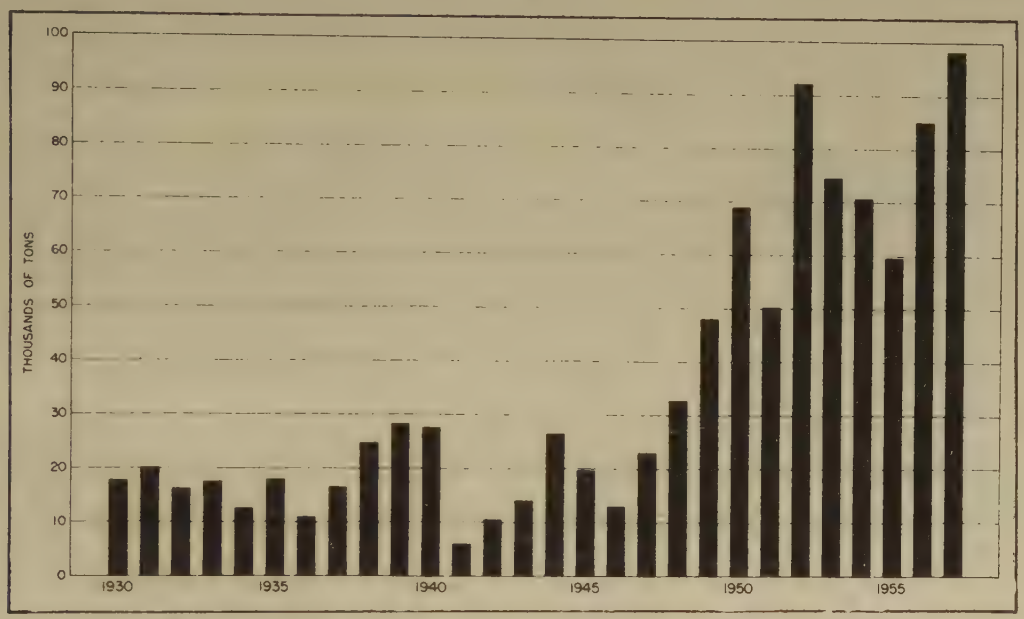

Fig. 3 - Total annual albacore landings (United States and Japan), 1930-57.

Following the recovery of the fishery around 1938, there have been some marked fluctuations in the landings from year to year, reaching relatively high levels in 1944 (26,000 tons) and in 1950 (36,000 tons). After peak landings in 1950, there was a gradual drop to a low of 13,500 tons in 1954. But in the last few years landings have again increased.

The Japanese began to export albacore to the United States in 1931 following the drastic drop in landings on the United States west coast. Prior to the establishment of this important export market, which has grown steadily over the years and has in recent years become a matter of serious concern to the United States fishing industry, Japanese fishermen had never sought this fish for domestic consumption (Van Campen[1/]). The albacore is considered too soft in texture, too pale in color, and even tasteless, by the Japanese who customarily eat tuna raw ("sashimi"). The export market, which developed in response to the failure of the California albacore fishery in the late 20's, has continued to grow because of the increasing demand in the United States for canned albacore which could not be supplied by United States landings alone.

Like most large commercial fisheries, the albacore fishery in the United States occasionally suffers serious setbacks due to economic difficulties. For example, Samson (1955) points out that had price disputes not hampered fishing in the middle of the 1955 season, albacore production that year could have been much greater because there apparently were unusually heavy runs of albacore at that time. However,

1/See page 2.

it appears that in general the West Coast landings have fluctuated according to the availability of fish along the West Coast.

Japanese landings of albacore are also dependent upon economic considerations, to perhaps an even greater extent than the United States fishery. This situation is aggravated by the fact that nearly all albacore are exported. It has been reported that when an unfavorable export situation exists, and prices are low for albacore taken in the spring live-bait fishery, many of the boat owners are reluctant to go into winter long-lining for albacore, and may instead, turn their efforts toward fishing in the tropical Pacific or engage in some other fisheries such as that for mackerel (Anonymous 1958). In the live-bait fishery also, it is possible that when conditions are unfavorable many of the boats may continue fishing for skipjack rather than fish for albacore. It is not within the scope of this paper, however, to deal with the complex economic considerations.

The Japanese landings fluctuated little between 1930 and the onset of World War II, averaging a little over 16,000 tons a year (fig. 2). Fishing for albacore apparently continued for a few years after the start of the war but no statistics are available. Following the war there was a very rapid recovery, and by 1950 the production exceeded the prewar levels. The rapid development of this fishery can be seen more clearly if we examine the average landings for different periods. The 1930-35 landings averaged 16,706 tons a year, and during the 1936-40 period the average was 16,110 tons. After the war, from 1946 to 1950, the average dropped slightly to 14,344 tons. The average landings in the most recent period, 1951 to 1957, climbed to 56,771 tons, or more than three times those of prewar years.

In comparison with this increase in the level of landings, the United States landings increased at a far less spectacular rate. From an average of 5,562 tons a year in the 1936-40 period, during which there was a recovery from the virtual failure in the fishery, landings increased to an average of 22,755 tons a year during the postwar period of 1946-50. In the recent period, 1951-57, the average landings have been 18,976 tons, thus showing a slight decrease from the preceding period.

The combined yearly albacore landings of the United States and of Japan for 1930 to 1957 are shown in figure 3. With the exception of the war years, total landings of the two countries have shown a rather marked upward trend. From average annual landings of just under 17,000 tons in the 1930-35 period, the present level has reached approximately 76,000 tons (1951-57). This fourfold increase over the prewar period reflects the greatly increasing United States demand for canned tuna, of which albacore is the most highly prized.

That Japan is the leading producer of albacore is clearly seen in figure 2. Only during the war years and a few years following did the United States take the lead in total production. From 1951 to 1957, Japan accounted for an average of 75 percent of the total combined landings of the two countries.

TRENDS IN THE JAPANESE FISHERIES

TEMPERATE NORTH PACIFIC FISHERIES: Annual Japanese landings of the spring live-bait and winter long-line fisheries are compared in figure 4. Similar statistics are unavailable for 1938-1945. From 1931 through 1937 there was a steady decline in the landings of the live-bait fishery. The long-line fishery, on the other hand, showed some increase around 1935. This increase was due largely to a concerted effort made by the Japanese Government to compensate for the decline in pole-and-line catch by exploring grounds farther offshore beginning in 1933. The exploratory program resulted in an extension of the long-line grounds eastward. The landings correspondingly increased to a point where this fishery constituted the major source of albacore to the Japanese for a few years following.

In recent years the live-bait fishery has come to dominate tuna landings. Between 1951 and 1957, the live-bait fishery accounted for an average of 64 percent of the landings made by these two fisheries. This increased yield of the live-bait fishery has also been accompanied by an extension of grounds eastward, which was made possible by the addition of larger vessels in the fleet.

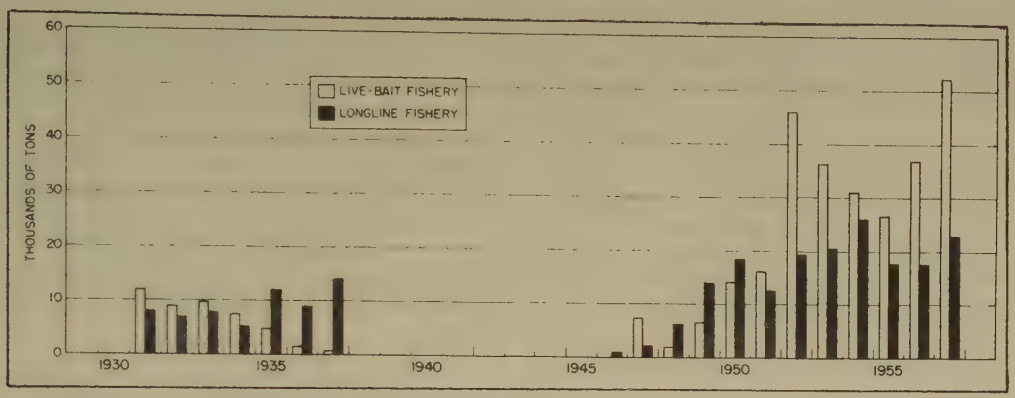

Fig. 4 - Comparison of the landings of the Japanese live-bait and long-line albacore fisheries. (Long-line landings do not include fish taken on mothership-type operations or by vessels based in foreign ports.)

The 1957 figures are estimated from monthly statistics provided by the Nankai Regional Fisheries Research Laboratory, Japan.

FISHERIES IN THE TROPICAL PACIFIC: For convenience in discussing the catch statistics of tropical albacore, two distinct fisheries have been described for the tropical Pacific, (1) the mothership-type fishery, and (2) the foreign-based fishery. In (1) the fishing vessels operate around a mothership using the latter as a base, and in (2) the vessels work out of a foreign land base. But there is little basis for considering these as separate fisheries. Both exploit subsurface tunas by the long-line method, and there are no clear seasonal or area differences that would make each distinct from the other.

While not given a special designation like the other fisheries, the numerous independent Japanese long-liners which ply the waters of the tropical Pacific and eastern Indian Oceans are nevertheless important contributors of long-line albacore. These vessels, capable of operating for considerable periods without logistic support of motherships or land bases, account for significant quantities of tropical tuna. Their contributions are reflected in the tremendous increase in overall Japanese albacore landings (fig. 2).

The annual albacore landings by the mothership-type operations are given in table 1. For purposes of comparison the landings of yellowfin tuna (Neothunnus macropterus) are also shown.

Table 1 - Albacore and Yellowfin Landings of Japanese Mothership Fleets[1/]

Year	Albacore	Yellowfin
	. . . (Short Tons) . . .	
1956	4,069	2,229
1955	5,409	3,221
1954	3,920	4,285
1953	321	4,794
1952	79	4,429
1951	137	5,432
1950	49	4,109

1/ 1957 figures are unavailable.
Sources: Annual Reports of Catch Statistics on Fishery and Agriculture, Statistics and Survey Division, Japanese Ministry of Agriculture and Forestry, 1955 edition; 1956 figures, source cited as the Japanese Fisheries Agency.

Yellowfin dominated the mothership landings during the first few years of operation, while albacore has become an important constituent only in more recent years. This is mainly a reflection of the shift in area of operations of the fleets, which during the period of restrictions exploited waters of the U. S. Trust Territory of the Pacific Islands, lying to the north of the Equator, where the predominant tuna species are the yellowfin and big-eyed (Parathunnus sibi) tunas. Probably

because of the favorable acceptance of long-line caught albacore in the market, many of the fleets now operate in more southern waters, such as in the vicinity of Fiji and Tonga Islands, where albacore are found in great numbers. In 1955 and 1956, albacore landings outweighed yellowfin landings by 40 and 45 percent, respectively. Unquestionably there has been a shift in emphasis on the part of the Japanese toward a higher production of albacore in recent years.

Table 2 - Albacore and Yellowfin Landings of Japanese Foreign-Based Vessels

Year	Albacore	Yellowfin
	. . . (Short Tons) . . .	
1957	6,236	1,719
1956	3,781	2,159
1955	3,228	2,895
1954	270	638

Sources: 1954 and 1957 figures are from records of cannery in America Samoa. Weights of gilled and gutted yellowfin were roughly adjusted to round weights by adding 9 percent; 1955 and 1956 figures ascribed to Japanese Fisheries Agency.

Table 2 lists the annual landings of the foreign-based vessels. These are essentially landings of long-liners based in American Samoa since the New Hebrides operation did not begin until November 1957. The albacore and yellowfin are also the major tuna species taken by this fishery. Here again, a shift in dominant species is seen, similar to that shown by the mothership-type fishery.

In 1954 yellowfin was the predominant species, and albacore accounted for only 30 percent of the combined albacore and yellowfin landings. In 1955, albacore accounted for 53 percent; in 1956, 64 percent; and in 1957, 78 percent of the combined landings of these two species. Thus there has been a gradual tendency for albacore to figure more importantly in the Samoa catch each year since the inception of this fishery.

This shift has come about from a movement away from the old fishing grounds, which in 1954 and early 1955 were chiefly in the vicinity of Samoa and to the north. As vessels began working in more distant and southerly waters (e.g. Tonga Islands), catches of albacore increased noticeably. Today, more and more fishing is done in waters productive of albacore, a shift in emphasis which can be attributed largely to the good canning quality of these long-line caught tropical albacore and the higher price this species generally commands.

RELATIONSHIP OF ALBACORE TAKEN IN THE VARIOUS FISHERIES

At present little is known of the relationship of albacore found in different parts of the Pacific Ocean. As mentioned, the bulk of the Pacific albacore production is from the Temperate Zone of the North Pacific with Americans and Japanese conducting seasonal fisheries for the species. Available evidence from tag returns leads us to believe that there is a single population of albacore in the North Pacific (Blunt 1954, Ganssle and Clemens 1953, and Otsu MS[3/]). Albacore tagged off the United States west coast have been retaken off the coast of Japan, and those tagged in mid-ocean north of Hawaii have been retaken in the Japanese fishery as well as in the United States west coast fishery, thus showing that there is considerable movement of fish from one fishery to the other. The tag returns, therefore, support the contention that the Americans and Japanese are both exploiting a single, intermingling population of albacore in the Temperate Zone of the North Pacific.

Furthermore, examination of gonads of albacore from various areas has shown that the Temperate Zone North Pacific fish are without exception juveniles, or are sexually-immature adults which evince no signs of incipient or past spawning (Otsu and Uchida, in press). It appears then that the North Pacific albacore are but a segment of a much larger population which is ecologically separated into spawning and nonspawning components. This same study suggests that the spawning segment of the population occurs in tropical or subtropical waters. There may be a movement

3/Otsu, T. Manuscript. Albacore Migration and Growth in the North Pacific Ocean as Estimated from Tag Recoveries. Prepared for publication in Pacific Science.

of the larger fish from Temperate Zone waters into subtropical waters, possibly into the North Equatorial Current area where some spawning appears to take place (Ueyanagi 1957, Otsu and Uchida, in press), or possibly farther south into the equatorial Pacific. It may be that these large fish spread out over a vast area in the tropical Pacific, or, as postulated by Suda (1956), the albacore occurring in the tropical South Pacific may comprise a spawning group of another population to be found in the southern hemisphere. The latter implies that the north Temperature Zone albacore is unrelated to the albacore of the tropical South Pacific now being exploited by the Japanese.

Obviously, there is much to be learned about the population structure of this valuable resource. While there does not appear to be any serious problems of overexploitation facing any of the Pacific albacore fisheries at the present time, a knowledge of the population structure would be of vital importance in formulating conservation or management policies should they prove to be necessary. If there are several discrete populations of albacore, the depletion of one would of course not affect a fishery based on another population. If however, the Americans and the Japanese are exploiting a single population of albacore in the North Pacific, then the problems concerning the resource would necessarily be of mutual concern. In this situation the effect of overexploitation would not be confined to whatever fishery is responsible, but would be shared by the other fishery as well. It is clear that the knowledge of the population structure constitutes a valuable adjunct to the understanding of problems inherent in these fisheries.

Although not well documented, frequent reference is made to the apparently close relationship between the major North Pacific albacore fisheries, that good and bad years appear at the same time in both the American and Japanese fisheries. If such a relationship does exist, it would be well worth noting because the American fishery follows the Japanese live-bait fishery in time, and the American industry is in a position to benefit by an advance indication of the relative magnitude of the season's landings.

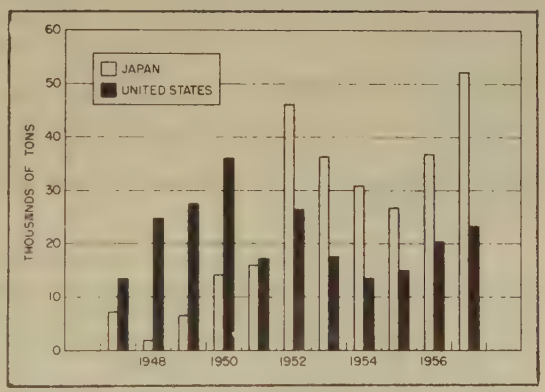

Fig. 5 - Comparison between the landings on the United States west coast and by the Japanese live-bait fisheries, 1947-57.

In figure 5, landings on the United States west coast and by the Japanese live-bait fisheries are compared. For the more recent years, after 1950, the landings show some corresponding trends. For example, 1952 was a particularly good year in both fisheries, and 1954 and 1955 were relatively poor in both. This apparent relationship breaks down if the earlier years are included.

From the point of view of fish sizes exploited by these two fisheries, with the American fishery taking smaller fish in general than the Japanese fishery (Otsu, T.[3]), it would appear more reasonable to expect correspondence in landings not on a year-to-year basis, but rather between year N in the American fishery and year N+1 or N+2 in the Japanese fishery if the fluctuations in annual landings are reflections of actual abundance. This assumes that availability factors remain the same from year to year, which of course is not entirely true for the albacore. While it is possible that an exceptionally good year in the Japanese fishery would be followed by a good season in the American fishery, or vice versa, there are probably other factors which affect the occurrence of fish in the two fisheries to such an extent that any clear relationship in the landings could not be expected.

3/See page 8.

DISCUSSION

It has not been possible to compile satisfactory statistics on fishing effort to be examined in relation to the gross landings statistics presented in this report. It is known that following the war the Japanese have continued to enlarge their fishing fleets, and have built larger vessels capable of fishing in more distant waters. A recent survey conducted by the United States Department of the Interior (Anonymous 1958) found that the number of Japanese fishing vessels had doubled since 1951. This expansion, although not applied to the albacore fishery alone, has nevertheless affected the catch of albacore, particularly in that portion of the landings accounted for by the numerous independently-operating long-liners fishing in distant tropical waters. While the Japanese have increased their fishing capacity with a view toward increased production, the situation on the United States west coast has been quite different. According to the same survey, the United States albacore fleet has been reduced from 3,000 to 1,000 boats in recent years. The general situation can perhaps be deduced from conditions prevailing in the tuna industry as a whole. According to Samson (1957), the 1957 California tuna clipper fleet (vessels over 50 gross tons) numbered only 146 as compared to the 1951 total of 210. Similarly, the tuna purse-seine fleet underwent a drastic reduction of from 163 vessels in 1947 to 58 by the end of 1957.

The available data on fishing effort do not permit a detailed analysis of the effect of effort on the level of landings. Judging from gross catch statistics alone, it might be reasonable to deduce, however, that there was perhaps a parallel increase in catch with increasing effort in the Japanese fishery. The fact that their present landings are triple those of prewar years attests to this. It is of course possible that the catch has not kept pace with effort, and that there is a general leveling off of catch relative to the rising effort. It is not possible to determine this without detailed data on effort, but in the face of the continued high level of production in the last several years, it seems unlikely that exploitation has seriously affected the albacore stock.

While it is true that the Japanese have had to build larger vessels and go farther from Japan in order to meet their catch goals, it must be realized that the present level of albacore landings is significantly higher than the prewar level. Their two North Pacific fisheries appear to be quite stable, even at the present high level of catch. There is no indication of a declining resource. While the South Pacific fisheries are relatively recent in origin and may not have stood the test of time, the present status of the Samoa-based fishery or the mothership operations is encouraging as far as albacore catch is concerned.

Catch statistics, although not reliable when considered alone, indicate that the albacore resources in the Pacific are extensive, and that production can probably be increased particularly by exploitation of new grounds, as shown by the Japanese in the South Pacific. In the absence of catch per unit-of-effort data it is not possible to evaluate the situation in the present North Pacific grounds with any degree of confidence. While the annual fluctuations in the landings of these fisheries from "good" through "poor" years may possibly indicate that much heavier exploitation will not substantially increase production, it also appears unlikely that these fisheries are being overexploited at present. All indications on the present status of the albacore fisheries point to a parallel rise in effort and catch through a background of erratic natural fluctuations.

SUMMARY

1. Catch statistics are presented for the major Pacific albacore fisheries which include: (1) the United States west coast summer to fall fishery, (2) Japanese winter midocean long-line fishery, (3) Japanese western Pacific spring to summer live-bait

fishery, (4) Japanese tropical Pacific mothership fishery, (5) Japanese tropical Pacific foreign-based fishery.

2. The American fishery has been beset with marked fluctuations in production. With the establishment of the canning industry in California in 1903, albacore landings increased until 1925 when the species suddenly failed to appear on the west coast in its usual abundance. Landings were negligible until around 1938. In the last decade, the landings have shown a downward trend following the peak year of 1950 with 36,000 tons until 1954 when approximately 13,500 tons were landed. The last few years again showed a trend toward greater catches.

3. The Japanese landings of albacore, which averaged a little over 16,000 tons a year between 1930 and the onset of World War II, have in recent years increased to an average of more than 55,000 tons (1951 to 1957), or more than three times those of prewar years. This tremendous increase reflects the increasing demand in the United States for canned albacore, since the bulk of the Japanese landings are exported to the United States for that purpose.

4. Japan accounts for an average of 75 percent of the combined albacore catch of the two countries, United States and Japan.

5. Of the several Japanese fisheries for albacore described, the two oldest, and also the most important, are the winter long-line and the spring-summer live-bait fisheries. Both of these fisheries are conducted in the Temperate Zone of the North Pacific. The live-bait fishery is the leading source of Japanese albacore.

6. The tropical fisheries are relatively recent in origin. Two distinct tropical fisheries, the mothership and the foreign-based, are described. There is a third category, not considered in this report due to lack of separate statistics, and this is the group of independent Japanese tuna long-liners which operate in tropical waters without benefit of either a mothership or a foreign base. These vessels undoubtedly account for significant quantities of albacore. In the tropics all albacore are taken by the long-line method, and seasons are not clearly defined as in the Temperate Zone North Pacific fisheries. It is shown that albacore has come to figure more prominently in the landings of these fisheries in recent years, and this is believed due to a purposeful shift in species emphasis.

7. Since frequent reference is made to the apparently close relationship between the American and Japanese fisheries, that good and bad years appear at the same time in both fisheries, the landings of the American fishery were compared with landings of the Japanese live-bait fishery. A relationship as alluded to is not clearly evident.

8. Although detailed data on albacore fishing effort are not available, the general situation prevailing in the tuna industries of the two countries may be indicative of any general trends. This shows that the Japanese have been building larger vessels and have continued to enlarge their fishing fleet ever since the end of World War II. In addition, they have expanded their fishing grounds to include more distant waters. Along with this increasing effort, there was a parallel rise in the level of albacore landings. The situation is apparently quite different in the American albacore fishery and it is unlikely that there was any increase in fishing effort over the last few years.

9. Catch statistics of the various albacore fisheries show no evidence that exploitation has had any detrimental effect on the albacore stock. There appears to have been a parallel rise in effort and catch through a background of erratic natural fluctuations.

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AGE DETERMINATION OF ALBACORE BY THE VERTEBRAL METHOD

by
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ABSTRACT

An attempt was made to determine the age of central North Pacific and Hawaiian bacore, *Germo alalunga* (Bonnaterre), by counting rings in the vertebral centra, a method which some degree of success had been reported elsewhere. Results were negative cause of the impossibility of duplicating counts in successive readings or by different aders. It is concluded that the Albacore from these areas cannot be aged by the vertebral ethod with presently existing techniques.

INTRODUCTION

This is a preliminary report on a study termine the age and growth of Albacore, *alalunga* (Bonnaterre), taken from the s of the Hawaiian Islands and from the Pacific Ocean north and northwest of ii. This study is part of the Albacore ch program presently being conducted e Pacific Oceanic Fishery Investigations) of the U.S. Fish and Wildlife Service Public Laws 329 (80th Congress) and Saltonstall-Kennedy Act, 82nd Congress).

Several workers in the past have reported age and growth of Albacore as determined examination of the surface marking on the ral centra. Aikawa and Kato (1938) based studies on 10 large Albacore taken near ay Islands and five small fish taken off eastern Japan. Partlo (1955) made a more ehensive study based on vertebrae of sh taken during the 1950 fishing season he offshore waters of California, Oregon, ngton, and British Columbia. Figueras followed with a brief report based on ecimens taken off the coast of Galicia western Spain). Uno (1936a, b), without details of his technique, reported on sults of his study based on about a nd fish taken off the Japanese coast.

All of these workers either directly or ctly suggested the presence of rings on ner surfaces of the two hollow cones amphicoelous Albacore vertebra. They ded that each ring represented an annulus herefore, the number of rings was an tor of age. By measuring the distance he centre of the centrum to each ring, elieved they were deriving an estimate of the growth of the fish. Aikawa and Kato, Figueras, and Uno, as far as we can determine, have provided no evidence showing that the rings on the vertebrae are indeed "age rings" and annual in nature. Partlo hypothesized that the rings are true year marks by the following: (1) by assuming that the length groups in the size frequencies are age groups, he found that there was acceptable agreement between the mean length of fish assigned to each vertebral ring-class and the mean length of corresponding length-groups in the sample, and (2) there was agreement between the lengths of young fish calculated from vertebral measurements of older fish and the observed lengths of young fish. For the latter, Partlo, working with a subsample of 98 fish, found that the observed lengths were consistently greater than the calculated lengths because the fish were captured some time after the last ring was formed. Partlo concluded that "from the above it seems clear that the third and subseguent vertebral rings are produced annually. It is assumed, in the absence of contrary evidence, that the inner two rings are annual also."

In our study we attempted to evaluate the use of vertebrae to determine the age of Albacore taken in the North Pacific and in Hawaiian waters. Employing a wider size range of fish than had hitherto been used by any single worker, we hoped to extend previous findings to include the large fish landed in the Hawaiian Islands, and at the same time make a careful examination of the evidence appearing to indicate that the rings on the centra are true year marks. However, as will be shown, we were not able to duplicate or verify past results, nor did we find that we could use the vertebrae to age central North Pacific and

Indo—Pacific Fish. Coun., 7 (II—III): 49—52, 1957.

Hawaiian Albacore. The results of our study, though largely negative, be presented for the infomation of those who are presently engaged in similar studies and for others who may work on this problem in the future.

MATERIALS AND METHODS

While most of the past investigators used thoracic vertebrae for Albacore age determination, we selected the 15th and 16th caudal vertebrae. Our choice of the caudal vertebrae was based chiefly on accessibility, or the ease with which they could be acquired in the field or at the local fish markets. Furthermore, correspondence with other investigators engaged in similar studies indicated that caudal vertebrae showed as much promise as any other. Subsequent examination of each of the 38 vertebrae of an Albacore revealed no notable differences in the appearance of the concentric markings.

Our sample, collected between January 1955 and July 1956, consisted of vertebrae from 212 Hawaiian and 53 central North Pacific Albacore. The Hawaiian Albacore, taken by the longline fishery, were generally large, ranging in size from 93 to 128 cm. (33 to 93 pounds), while the central North Pacific albacore, taken by trolling, gill net, and longline, were smaller, ranging between 51 and 112 cm. (6 to 65 pounds).

The vertebrae were sectioned and prepared for examination according to the method described by Partlo. The cleaned and dried vertebra was cut longitudinally along the dorsoventral plane, but to one side of the median line, into two unequal parts. The larger of the two parts was then sanded down until the centre of the centrum was exposed. Additional cleaning and accentuating of the concentric rings were done by immersing the vertebrae in a one-percent solution of potassium hydroxide for 48 hours ; this was followed by preservation in 95-percent alcohol.

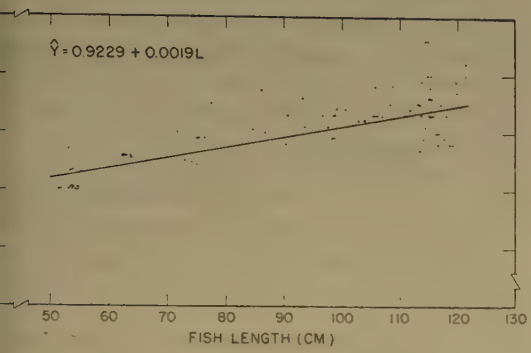
The Albacore vertebra is amphicoelous, or concave at both ends of the centrum. A sectioned vertebra reveals two cones whose vertices meet at or near the centre of the centrum with the bases forming the margins of the vertebra. On the inner surface of these cones are concentric rings running parallel to the outer margin of the centrum. These rings were described by Partlo as "narrow translucent zones separated by broad opaque zones similar to those described by Freidenfelt (1922) *Lucioperca*. In the Albacore the narrow z were observed not only as translucent b but also as eruptions or ridges on the cen surface. The innermost ring differed sli from the others but was nevertheless cl marked." In the course of our study we f that certain rings do appear as definite ri on the surface, while others appear as na translucent bands without any surface erup and still others are more suggestions of or bands. In addition to examining the tebrae under natural and incandescent l we experimented with polarized and var coloured lights but without achieving appreciable improvement in the appearan the rings. Various types of stains were t but here again the results were disappoi from the standpoint of improving the "re bility" of the rings.

CHANGE IN SHAPE OF VERTEBRAE W GROWTH OF FISH

In the course of examining a wide s of vertebrae, we observed that while the cones of a caudal vertebra are nearly the size in small fish, the posterior cone appe larger than the anterior among large fish dicating that the vertebra changes its s with growth of the fish. The lengths of two cones were measured and the ratio o two measurements was plotted against the of the fish (Fig. 1). While the ratio is n 1 : 1 in the smallest vertebrae examined of around 50 to 60 cm. in length), the post cone is definitely larger than the anteri the larger vertebrae. This changing propo is described by the rectilinear regression

$$\hat{Y} = 0.9229 + 0.0019\ L$$

where $\hat{Y}$ is the ratio of the two cones L is the fork length in centimeters. Alth the two cones of a caudal vertebra grow proportionately, each cone in itself exhib linear growth with growth of the fish. in working with a wide size range of ca vertebrae, it is important that any measuren of ring or vertebral radii to estimate gr increments of the fish should be con to either the anterior or the posterior c and not to averages of the two.



ig. 1. Ratio of the average length of the ior and anterior cones plotted against fish o demonstrate the disproportionate growth two cones of the amphicoelous vertebrae acore.

EADIBILITY OF VERTEBRAL RINGS

fter deciding upon the criteria to be follow- ne authors started on a series of indepen- ring counts and ring-radii measurements. al of nine series of counts and measure- resulted in agreements between any eries of as low as eight percent and only gh as 45 percent. There was poor agree- not only between counts of the two s but also between counts made by the person. Consistency was often not achi- even between counts of the anterior and ior cones of the same vertebra. While most disagreement was by one ring (31 to 50 nt), discrepancies of as many as four rings ed in many of the comparisons. Thus, und that we could not sātisfactorily dup- ring counts and therefore could not meet st prerequisite to the use of vertebrae ing Albacore. Our findings are in contrast tlo's, who reported that "counts of rings reproducible with high consistency."

We observed that much of the inconsis- in the counts could be attributed to the lty of distinguishing rings near the ver- the cone and also at the margin. This ot mean, however, that the rings on the l portion of the cones were clear and distinguishable, because here also many nstencies resulted.

SAMPLES FROM SMALL FISH

Age determination by means of hard parts frequently becomes more difficult and the method often breaks down completely in older fish. Since other investigators dealt largely with small fish, we concentrated our efforts on a group of similarly small fish (less than 90 cm.) in order to determine whether or not our difficulties were due to the use of larger, older fish. In one test consisting of two series of counts, we found that there was a 56 per cent agreement for fish less than 90 centimetres as compared with 30 per cent for those of larger size. The higher agreement with smaller fish is, of course, to be expected because of the fewer growth rings involved. After several more tests with series of small fish, we concluded that the counts were still far too variable to be acceptable as indicators of age.

DISCUSSION

A serious problem, especially in working with samples of small vertebrae, is to be strictly objective in making ring counts or measurements. Since there is a linear relationship between the vertebral radius and the body length of Albacore, it is almost impossible to make a reading without first forming an opinion as to how many rings a certain-sized vertebra should have. Because of the great variability in the appearance of the rings, we found it difficult to follow the criteria which we had established for judging the vertebrae. In retrospect, it may perhaps be said that our main difficulty was not so much in not being able to follow any set of criteria as not being able to develop acceptable criteria because of the variability of the rings. However stated, subjectivity was inadvertently introduced into our readings, particularly when we attempted to duplicate previous findings. This can be illustrated with an example: If the investigator measures the radius of the second ring at 5 mm. in a particular vertebra, and if all previous second-ring radii have fallen between 3 and 4 mm., he inadvertently looks closer at the vertebra for a second ring which he may have "missed". More often than not he will "find" the "missing" ring. In fact, we could locate "rings" almost anywhere on the centrum if we looked closely enough. While we could eliminate bias to a large degree when making counts, it was much more difficult to do so in the case of measurements.

CONCLUSIONS

Although vertebrae of small Albacore were somewhat more "readable" than those of the larger Albacore, we were unable to achieve sufficient consistency in our readings and measurements to validate this method of age determination. It appears that the Hawaiian Islands and central North Pacific Albacore cannot be aged by the vertebral method with presently existing techniques.

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SEXUAL MATURITY AND SPAWNING OF ALBACORE IN THE PACIFIC OCEAN

BY TAMIO OTSU AND RICHARD N. UCHIDA

FISHERY BULLETIN 148

From Fishery Bulletin of the Fish and Wildlife Service

VOLUME 59

UNITED STATES DEPARTMENT OF THE INTERIOR

FISH AND WILDLIFE SERVICE

UNITED STATES DEPARTMENT OF THE INTERIOR, Fred A. Seaton, *Secretary*

FISH AND WILDLIFE SERVICE, Arnie J. Suomela, *Commissioner*

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UNITED STATES GOVERNMENT PRINTING OFFICE • WASHINGTON • 1959

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. Price 20 cents.

Library of Congress catalog card for this bulletin:

Otsu, Tamio.

Sexual maturity and spawning of albacore in the Pacific Ocean, by Tamio Otsu and Richard N. Uchida. Washington, U. S. Govt. Print. Off., 1959.

iv, 287–305 p. illus., map, diagrs., tables. 26 cm. (U. S. Fish and Wildlife Service. Fishery bulletin 148)

"From Fishery bulletin of the Fish and Wildlife Service, volume 59."

Bibliography: p. 304–305.

1. Tuna fish. I. Uchida, Richard N., joint author. II. Title. (Series: U. S. Fish and Wildlife Service. Fishery bulletin, v. 59, no. 148)

[SH11.A25 vol. 59, no. 148] Int 59–11

U. S. Dept. of the Interior. Library
for Library of Congress

Library of Congress catalog card for the series, Fishery Bulletin of the Fish and Wildlife Service:

U. S. *Fish and Wildlife Service.*

Fishery bulletin. v. 1–

Washington, U. S. Govt. Print. Off., 1881–19

v. in illus., maps (part fold.) 23–28 cm.

Some vols. issued in the congressional series as Senate or House documents.

Bulletins composing v. 47– also numbered 1–

Title varies: v. 1–49, Bulletin.

Vols. 1–49 issued by Bureau of Fisheries (called Fish Commission, v. 1–23)

1. Fisheries—U. S. 2. Fish-culture—U. S. I. Title.

SH11.A25 639.206173 9–35239 rev 2*

Library of Congress [r55e½]

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ABSTRACT

This report presents the results of a study of gonadal development and spawning in the albacore, *Germo alalunga* (Bonnaterre). The study is based on examination of the reproductive organs, principally the ovaries from albacore collected in three general areas: the North Pacific, the Hawaiian Islands, and the central equatorial Pacific.

The ovaries were classified in three stages of relative maturity: early developing, late developing, and advanced, on the basis of the most advanced eggs present. According to this classification, the early developing category included the thin ribbonlike ovaries from sexually immature fish as well as ovaries from the larger, adult fish which showed no signs of egg development beyond this particular stage. The other two categories, on the other hand, included only ovaries from adult fish.

The North Pacific albacore were either juveniles or sexually dormant adults with early developing gonads. The Hawaiian albacore showed varying degrees of maturity from early developing to advanced, with the bulk of the ovaries in the late developing stage. The ovaries from central equatorial Pacific fish were in the early developing and late developing stages, with the early developing stage predominating.

Our data show that albacore taken north of Hawaii by research vessels of the Pacific Oceanic Fishery Investigations, as well as albacore taken by the Japanese in the spring live-bait and winter longline fisheries, and those in the American west coast summer fishery are nonspawning fish, either juveniles or adult fish whose gonads show no signs of incipient or past spawning. Albacore apparently do not spawn in the temperate waters of the North Pacific. On the other hand, it appears that the albacore in the region of the Hawaiian Islands and in the central equatorial Pacific represent a segment of the population which, after attaining a certain size in temperate waters of the North Pacific, moves south into tropical and subtropical waters to reproduce.

SEXUAL MATURITY AND SPAWNING OF ALBACORE IN THE PACIFIC OCEAN

By Tamio Otsu and Richard N. Uchida, *Fishery Research Biologists, Bureau of Commercial Fisheries*

ıe albacore, *Germo alalunga* (Bonnaterre), is ınmercially important tuna, valued highly for ɛcellent canning qualities. In the Pacific the r fisheries for this species are conducted by Japanese in an area extending from the coast pan to the vicinity of the International Date , and by the Americans along the west coast he United States. Tag recoveries during ıt years have shown that albacore undertake ısive migrations across the Pacific (Ganssle Clemens 1953, Blunt 1954, Otsu and Uchida), thus suggesting that these major fisheries be dependent on a single population.

bacore are also widely distributed throughout ropical Pacific, but in this region they are ally taken incidental to the catch of other es of tuna. It is not known whether albacore ıe tropics belong to the same population as of temperate latitudes, or whether they form of another population. According to present ledge, albacore do not spawn in temperate rs. Information on the areas of spawning t provide a clue to the general distribution of populations that support the American and ıese albacore fisheries.

ıe research program of the Pacific Oceanic ry Investigations (POFI) of the Bureau of nercial Fisheries has included a study of gon- development and spawning in the albacore, ı has been financed by the Saltonstall-Ken- Act (Public Law 466, 83rd Congress). The ıt report on the albacore is based on examina- of the reproductive organs, principally the es, collected in three general areas: the North c. the Hawaiian Islands, and the central orial Pacific. Important differences in gonad opment were noted for fish from these three

The size at which albacore attain sexual rity was determined, and what appears to be ior spawning locality can now be defined.

—Approved for publication January 13, 1958. Fishery Bulletin 148.

We gratefully acknowledge the contributions of the following persons: R. S. Shomura and B. Wyatt who collected ovaries at the Honolulu auction markets; the managements of the United Fishing Agency, Ltd., and the Hawaii Fishing Co., Ltd., and the several fish dealers who permitted us to sample the albacore landings; Shoji Ueyanagi of the Nankai Regional Fisheries Research Laboratory in Kochi, Japan, who sent us samples of ovaries; and H. S. H. Yuen for valuable suggestions pertaining to sampling procedure.

SOURCE OF MATERIALS

NORTH PACIFIC

A total of 126 gonads from both sexes was collected between January 1955 and November 1956 in the North Pacific on POFI's exploratory fishing cruises (table 1 and fig. 1). Most of the sampled fish, ranging in length from 50 to 112 cm. (weight, 6 to 65 lbs.), were taken at the surface by gill nets or trolling; the few albacore larger than 87 cm. were taken exclusively on longline

TABLE 1.—*The number of albacore gonads obtained in the three areas* [1] *in various years*

Month	North Pacific				Hawaii		Central Equatorial Pacific			
	1955		1956							
	Male	Female	Male	Female	1955	1956	1952	1953	1956	1957
January	4	5	0	0	0	0	0	0	0	3
February	2	1	0	0	0	0	2	11	0	8
March	0	0	1	1	0	0	1	3	0	0
April	0	0	0	4	0	0	0	0	0	0
May	0	0	0	0	2	0	0	22	0	0
June	0	0	0	0	18	2	0	0	0	0
July	0	0	5	6	5	9	0	0	0	0
August	4	9	10	12	5	1	0	1	1	0
September	2	0	0	1	1	7	0	0	7	0
October	6	5	3	3	1	1	1	0	0	0
November	0	0	24	18	0	4	6	0	0	0
December	0	0	0	0	0	0	0	0	0	0
Total	18	20	43	45	32	24	10	37	8	11

[1] Fish of both sexes were sampled in the North Pacific but only females in the other two areas.

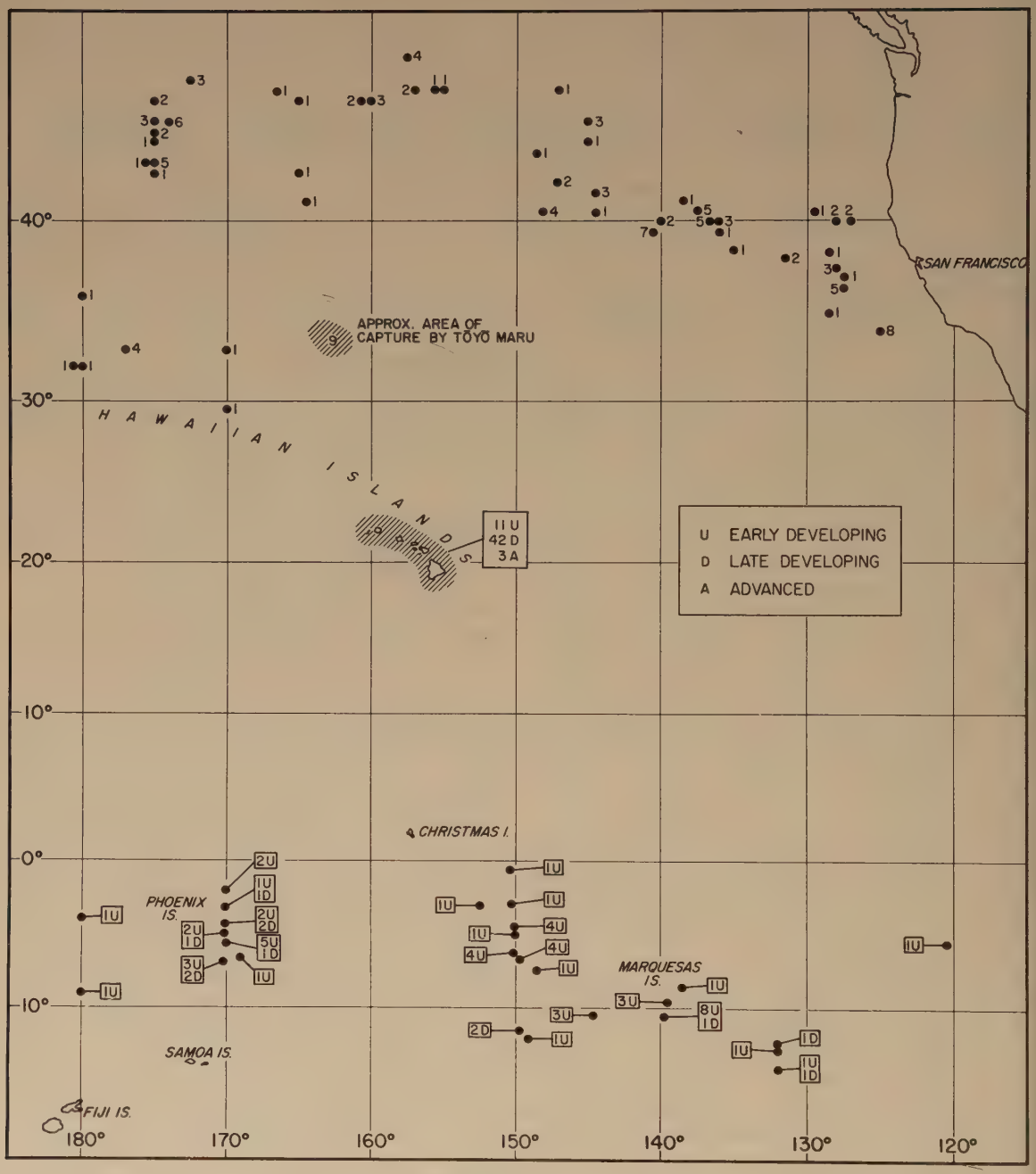


FIGURE 1.—Localities at which albacore gonads were collected. The Hawaiian and central equatorial Pacific sam consisted only of ovaries (stages of development shown); the North Pacific samples included testes and ovaries of which were in the early developing stage. (U=early developing, D=late developing, A=advanced stage)

(fig. 2). Immediately after the fish were landed the gonads were removed and preserved in 10-percent formalin. Data recorded were the date and locality of capture, fork length (weight was not always recorded), and the type of fishing gear.

In addition to the albacore taken on POFI vess we examined ovaries from a catch of alba landed in Honolulu by a Japanese longline ve the *Tōyō Maru*, in January 1955. This ve reportedly obtained her catch northwest of

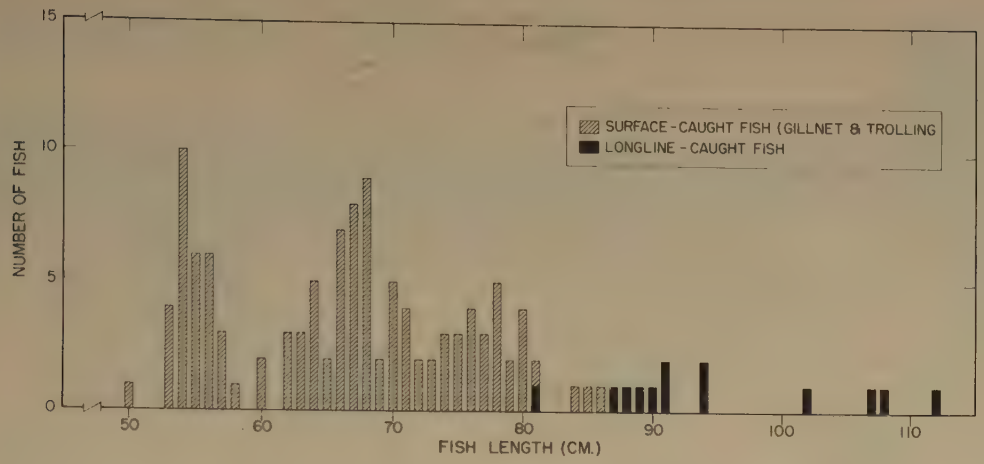


FIGURE 2.—Sizes of albacore sampled in the North Pacific.

vaiian Islands in the general area shown in re 1.

HAWAIIAN ISLANDS

varies from 56 fish ranging in length from 93.1 12.4 cm. (weight, 33 to 62 lbs.) were obtained 955 and 1956 from landings of the Hawaiian line fishery (table 1, fig. 1). These fish were ured within 20 miles of the main Hawaiian nds, mostly during the months of June to ember. A detailed description of this fishery ven by June (1950) and Otsu (1954). These core and those taken by the *Tōyō Maru* were pled at the auction markets of the United ing Agency, Ltd., and the Hawaii Fishing Co., , both in Honolulu. The ovaries were pre- ed in 10-percent formalin. Data obtained for fish were the date of landing, locality of ure, fork length, and weight.

CENTRAL EQUATORIAL PACIFIC

ne bulk of the samples from the central torial Pacific was obtained from three areas: between the Equator and 7° S. latitude along W. longitude; (2) between the Equator and S. along 150° W. longitude; and (3) from the ral region of the Marquesas Islands, 132° W. 0° W. longitude (table 1, fig. 1). A total of male albacore, all captured on longline on I cruises, was sampled between February and February 1957; these fish ranged in h from 84.6 to 104.8 cm. (weight, 29 to 54 In general, sampling in this area was dic both in space and in time. The method ampling the ovaries was similar to that described for the collection of gonads in the North Pacific.

DESCRIPTION OF THE GONADS

TESTES

The testes are paired, elongate organs suspended by the mesorchium in the body cavity. They are thin and ribbonlike in immature fish but with advance in maturity, they develop into somewhat flattened, whitish-yellow organs which are relatively solid. Their products are collected by a series of small ducts, vasa efferentia, leading posteriorly to a larger duct, the vas deferens, which opens to the exterior through the urogenital orifice.

June (1953) examined both the testes and ovaries in his study of the spawning of yellowfin tuna in Hawaiian waters but found that for this study "the testes were not suitable because no quantitative measure of their sexual products could be found that would provide reasonably accurate estimates of their relative stages of development." We found this to be true for the albacore also, and the testes were therefore merely designated in this report as immature or mature on the basis of their size and the presence or absence of milt.

OVARIES

The ovaries, like the testes, are paired, elongate organs suspended from the dorsal wall of the body cavity by the mesovarium. In immature fish, the ovaries are ribbonlike (fig. 3), may measure as little as 2 or 3 millimeters in diameter, and closely resemble the immature testes in appearance.

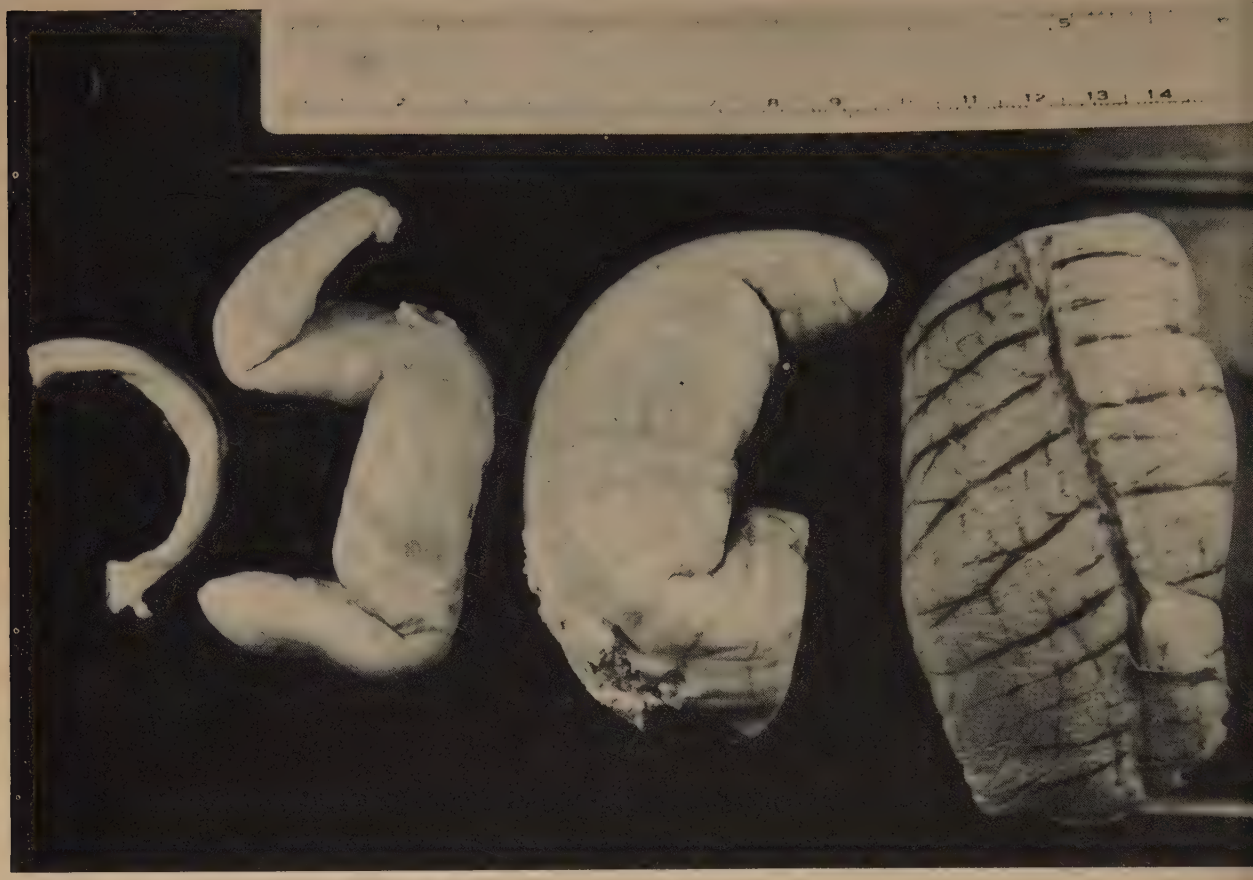


FIGURE 3.—Albacore ovaries in various developmental stages (only part of each ovary is shown). Left to right: a ribbo like ovary taken from a sexually immature, 75.8-cm. fish (ovary weight 9 grams); an early developing ovary fron 99.2-cm. fish (ovary weight 74 gms.); a late developing ovary from a 98. 5-cm. fish (ovary weight 275 gms.); and advanced ovary from a 107.6-cm. fish (ovary weight 916 gms.). Photograph by H. Yoshida.

They become progressively enlarged in length and girth as the fish attain sexual maturity, and with the final ripening of the eggs, they may attain a diameter of more than 40 mm. In the more advanced stages, the ovaries are nearly circular in cross section and the right ovary is usually slightly larger than the left. They have a ribbed internal cavity throughout their length and unite posteriorly with a thick-walled oviduct which opens exteriorly through the urogenital orifice.

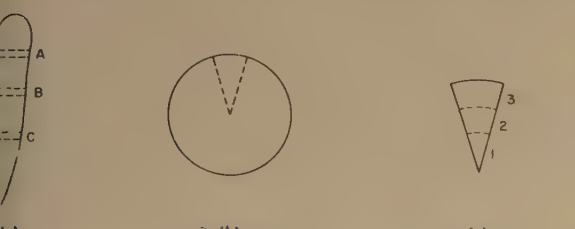
SUBSAMPLING THE OVARY

An objective method for determining the degree of maturity of an ovary is to measure the diameters of the constituent eggs. In order to reduce the amount of work involved in measuring the tremendous number of eggs within an ovary, it was necessary in our study to resort to subsampling. To subsample an ovary with confidence, however, requires that the distribution of eggs of vario sizes throughout an ovary as well as differenc between the two ovaries of a pair be determine

The procedure followed in this study was general similar to that described by Yuen (195 who investigated the maturity and fecundity the bigeye tuna in the Pacific. Eggs from sample were measured in a Sedgewick-Raft counting chamber ruled with parallel guide lin The parallel lines prevented duplicate measur ments of the same egg. Measurements we made to the nearest micrometer unit (0.0167 mm using an ocular micrometer. Because the form lin-preserved eggs of the albacore are not perfect spherical, we adopted the method of Clark (193 June (1953), Yuen (1955), and others of measuri the random diameter parallel to the ruled lines the counting chamber in whatever axis the e lies.

STRIBUTION OF MATURE EGGS WITHIN AN OVARY

everal tests were conducted to evaluate pling procedures. First, it was thought neces- to determine whether advanced eggs were ly distributed within an ovary. For this thin cross sections were taken from the rior, middle, and posterior parts of the right ber of one of the most advanced ovaries in the ction (fig. 4a). The cross sections were



RE 4.—Schematic representation of method used to tain test samples for determining most efficient sam- ng procedure.

led A, B, and C, respectively. A triangular on was then obtained from each of the three s sections (fig. 4b). Each triangular section further subdivided into three subsamples esenting, respectively, the center, mid-region, periphery of the ovary (fig. 4c). Thus, for on A there were positions A_1, A_2, and A_3; for on B, positions B_1, B_2, and B_3; and for section ositions C_1, C_2, and C_3. These samples were hed to the nearest 0.001 gram. All of the in the most mature group were then measured. weights and measurements are given in table 2. n analysis of variance (table 3) indicated a ficant difference ($P<0.05$) between positions he mean egg diameters but none between ons. The diameter means for sections A, B, C were 0.842 mm., 0.848 mm., and 0.842 mm., ectively. The results showed that for sec- s A and B, the mean egg diameter was largest ne periphery of the ovary. The situation was rsed for section C where the mean diameter least at the periphery and greatest near the ral lumen (table 2). It has not been deter- ed whether the differences between positions eal or an artifact of preservation.

ne number of eggs in the most advanced group e expected from 0.1 gram of each sample was

TABLE 2.—*Frequency distributions of diameters of the most advanced group of eggs from the various parts of an ovary (albacore No. 42—Hawaii)*

Diameter (in millimeters)	Sample No.								
	A_1	A_2	A_3	B_1	B_2	B_3	C_1	C_2	C_3
0.668	0	0	0	0	0	0	0	0	1
.685	0	1	0	1	0	0	0	1	1
.701	2	3	2	1	1	0	1	0	2
.718	1	4	4	1	0	1	2	1	2
.735	0	0	4	1	1	0	2	3	4
.752	1	7	3	1	1	1	2	8	9
.768	5	16	5	2	5	1	6	12	12
.785	11	13	10	5	2	1	7	13	10
.802	14	16	15	6	10	7	9	17	13
.818	14	16	15	9	9	4	12	11	14
.835	23	18	23	12	14	6	22	28	22
.852	13	22	13	15	14	7	23	14	19
.868	15	14	16	10	13	16	20	16	17
.885	10	18	9	12	7	5	13	10	12
.902	1	8	13	3	5	1	11	12	5
.918	2	11	8	1	6	3	6	6	6
.935	2	3	7	1	2	4	4	3	6
.952	1	3	5	2	2	2	3	4	0
.969	1	3	6	1	2	0	2	4	3
.985	0	2	1	0	0	1	1	1	3
1.000	0	1	2	0	0	0	1	0	2
Sum	116	179	161	84	94	60	147	164	163
Mean diameter (mm.)	0.833	0.838	0.850	0.842	0.848	0.858	0.850	0.838	0.837
Sample weight (gms.)	.053	.088	.080	.039	.047	.034	.088	.078	.070

then calculated from table 2 and tested by analysis of variance (table 4). The results showed that there was no significant difference ($P>0.05$) in the relative numbers per unit weight of ovary between sections A, B, and C.

A comparison was made of the egg-diameter frequencies of the right and left ovaries (albacore No. 74, Hawaii). A random sample was obtained from the central section of each ovary and all eggs larger than 10-micrometer units (0.167 mm.) were measured (table 5). The comparison resulted in a chi-square of 19.77 ($P=0.9$, 30 *d. f.*[1]) indicating a general similarity in the distributions between the two ovaries.

The results of the various tests suggested that representative samples of an ovary could be obtained anywhere along its length, provided a

TABLE 3.—*Analysis of variance of diameters of the most advanced eggs from different parts of the ovary (albacore No. 42, Hawaii)*

Source of variation	Degrees of freedom	Sum of squares	Mean square
Between sections	2	40.53	20.27
Positions within sections	6	165.85	*27.64
Individuals within positions	1,159	13,770.45	11.88
Total	1,167	13,976.83	

*Indicate significant ($p<0.05$) mean square value.

[1] The last four classes in the frequency distributions were combined because of the low numbers.

random subsample was obtained from the cross section. It was also shown that either of the two ovaries could be used. The procedure routinely used was to measure a random subsample from the mid-section of an ovary.

TABLE 4.—*Analysis of variance of numbers of most advanced eggs from different parts of the ovary (albacore No. 42, Hawaii)*

Source of variation	Degrees of freedom	Sum of squares	Mean square
Between sections	2	156.24	78.12
Positions within sections	6	3,152.96	525.49
Total	8	3,309.20	

TABLE 5.—*Egg diameter frequencies of right and left ovaries from the same fish (albacore No. 74, Hawaii)*

Diameter		Frequency	
Micrometer units [1]	Mm.	Right ovary	Left ovary
10	0.167	259	282
11	.184	137	147
12	.200	124	122
13	.217	117	101
14	.234	107	108
15	.250	115	93
16	.267	82	71
17	.284	72	64
18	.301	75	75
19	.317	69	64
20	.334	51	51
21	.351	48	44
22	.367	54	43
23	.384	56	55
24	.401	45	51
25	.418	59	46
26	.434	40	32
27	.451	39	30
28	.468	47	32
29	.484	29	32
30	.501	32	33
31	.518	16	19
32	.534	15	21
33	.551	26	32
34	.568	27	29
35	.584	27	28
36	.601	18	25
37	.618	20	19
38	.635	19	13
39	.651	10	8
40	.668	6	4
41	.685	2	1
42	.701	3	1
43	.718	1	0
Sum		1,847	1,776

[1] 1 micrometer unit = .0167 mm.

DEVELOPMENTAL STAGES OF THE EGG

Eggs were classified as early developing, late developing, and advanced. The descriptions are based on formalin-preserved material.

Early Developing

This category includes the primitive eggs found in all ovaries and eggs in the beginning stages of development. The primitive eggs vary from about 0.01 to 0.13 mm. in diameter, possess relatively large nuclei, and are transparent. early development the eggs increase in size become semi-opaque from deposition of granules. The maximum diameter of eggs in early developing stage is about 0.4 mm.

Late Developing

In this stage, the eggs are completely opa from the heavy accumulation of yolk granu They now range from 0.4 to about 0.8 mm diameter.

Advanced

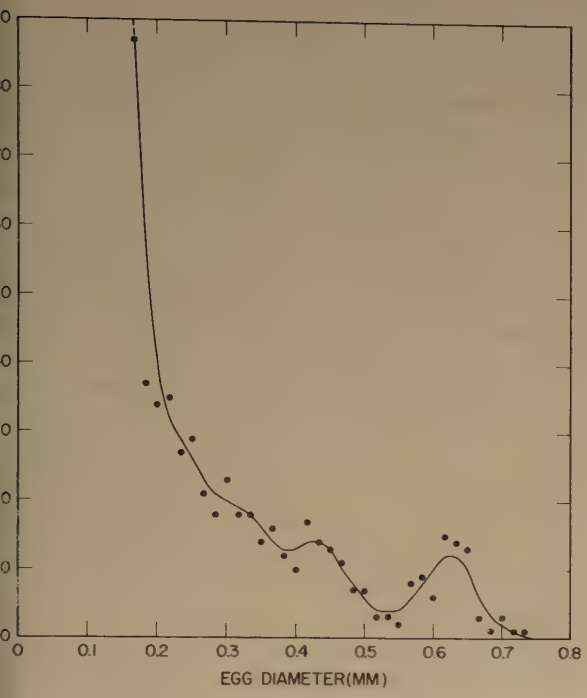
Distinct changes occur in the eggs as t approach ripeness. They lose their opacity become semitransparent; the nucleus cannot detected at this stage, and a conspicuous gold yellow oil globule appears. These advanced not fully ripe eggs range from about 0.7 to mm. in diameter in the most advanced sam available for study.

CLASSIFICATION OF OVARIES

The ovaries were classified into three cate ries of relative maturity, early developing, developing, and advanced, according to the sta of development of the largest eggs. In this cla fication, the early developing category inclu the thin ribbonlike ovaries from sexually im ture fish and ovaries from the larger adult which showed no signs of egg development bey the early stage. The other two categories, the other hand, included only ovaries from a fish (fig. 3).

As an example of the classification, a freque distribution of egg diameters from a fish clas as having late developing ovaries (fig. 5) is sho In addition to the mode of largest eggs cente at 0.63 mm., other groups of eggs are evid There are large numbers of early developing less than 0.4 mm. in diameter, and there is dence of a second group of late developing e one with a mode at 0.43 mm. Both groups late developing eggs were opaque, characteri of this stage.

An advanced ovary (fig. 6) has a mode of se transparent eggs centering at about 0.86 mm. addition there is one or more groups of late veloping eggs between 0.4 and 0.6 mm., possib less developed group at about 0.33 mm., as we the usual large numbers of early developing e



RE 5.—Frequency curve of 550 egg diameters measd from a late developing ovary of a 55-pound albacore ken in Hawaiian waters on June 15, 1955. The curve s derived by smoothing the data twice by a moving erage of three.

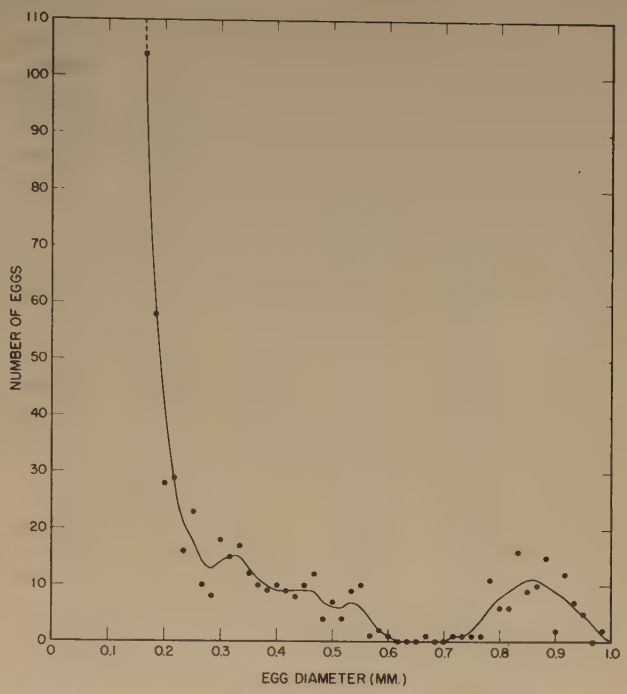


FIGURE 6.—Frequency curve of 550 egg diameters measured from an advanced ovary of a 47-pound albacore taken in Hawaiian waters on June 8, 1955. The curve was derived by smoothing the data twice by a moving average of three.

RESULTS OF GONAD EXAMINATION

NORTH PACIFIC

nce the gonads of albacore in the North Pacific generally thin and ribbonlike (early develop-, the sexes are often difficult to distinguish by s examination in the field. For this reason, ads of both sexes were collected and the sex determined in the laboratory by microscopical mination. Of the gonads of 126 fish examined, ere ovaries and 64 were testes.

he ovaries, the bulk of which weighed less than grams, contained only early developing eggs; maximum egg diameter measured was 0.25 . The most enlarged pair of ovaries (131 ns) obtained from the largest female fish pled (length 108.1 cm., weight 58 lbs.) con-ed eggs which measured less than 0.13 mm. in neter. The testes were also immature.

lthough large fish (longer than 90 cm.) were well represented in the sample, field observas of the gonad condition of longline-caught fish supplementary evidence that North Pacific were either sexually immature juveniles, or adult fish with early developing gonads. Table 6 lists the observations, based strictly on gross inspection, recorded by various members of the POFI staff. Presumably, the gonads of these large fish were sufficiently enlarged so that sex could be determined with some assurance. While the observations recorded as "spent," "spawned-out," and "recovering" might be questioned, there is little doubt that the "immature" fish, corresponding to our early developing category, were correctly designated. The observation dated January 28, 1955 (table 6), for a male albacore of 93.3 cm., is not necessarily indicative of advanced maturity. Male albacore taken in tropical and subtropical waters almost invariably contain some milt in the testes regardless of the size of the gonads. Brock (1943) found that milt could be squeezed from the testes of albacore captured off the coast of Oregon, but the females from this region were judged to be immature.

Our observations indicate that albacore in the central and eastern North Pacific are either sexually immature fish, or are adults which do not show signs of near-spawning. Partlo (1955)

TABLE 6.—*Field observations on sex and maturity of large albacore (over 90 cm.) taken on longline during POFI cruises to the North Pacific* [1]

Date of capture	Position of capture		Fork length, cm.	Sex	Description of gonad condition
	Latitude	Longitude			
Jan. 22, 1954	26°28′ N.	159°39′ W.	107.5	M	Immature.
Jan. 27	33°58′ N.	159°44′ W.	118.3	M	Do.
Do	33°58′ N.	159°44′ W.	112.7	M	Do.
Do	33°58′ N.	159°44′ W.	111.6	M	Do.
Do	33°58′ N.	159°44′ W.	110.7	M	Do.
Do	33°58′ N.	159°44′ W.	109.7	M	Do.
Do	33°58′ N.	159°44′ W.	107.4	M	Do.
Do	33°58′ N.	159°44′ W.	107.4	M	Do.
Do	33°58′ N.	159°44′ W.	106.1	M	Recovering.
Do	33°58′ N.	159°44′ W.	106.1	M	Immature.
Do	33°58′ N.	159°44′ W.	105.7	F	Spawned-out.
Do	33°58′ N.	159°44′ W.	104.5	F	Spent.
Do	33°58′ N.	159°44′ W.	102.5	M	Immature.
Do	33°58′ N.	159°44′ W.	99.4	M	Do.
Jan. 28	35°27′ N.	156°38′ W.	109.1	M	Do.
Oct. 24	38°40′ N.	175°27′ W.	107.6	F	Spent.
Dec. 9	34°23′ N.	159°48′ W.	113.6	M	Immature.
Do	34°23′ N.	159°48′ W.	110.7	M	Do.
Dec. 12	36°14′ N.	159°55′ W.	115.9	M	Do.
Do	36°14′ N.	159°55′ W.	96.8	F	Do.
Dec. 14	35°35′ N.	158°21′ W.	116.1	M	Do.
Do	35°35′ N.	158°21′ W.	114.8	M	Do.
Do	35°35′ N.	158°21′ W.	110.4	M	Do.
Jan. 17, 1955	33°50′ N.	179°44′ W.	104.5	M	Do.
Jan. 18	35°48′ N.	179°49′ W.	116.8	M	Do.
Do	35°48′ N.	179°49′ W.	113.0	M	Do.
Jan. 20	31°25′ N.	178°08′ W.	110.0	M	Do.
Jan. 28	30°42′ N.	175°01′ W.	93.3	M	Some milt in testes.[2]
Do	30°42′ N.	175°01′ W.	90.6	M	No milt in testes.

[1] Includes only those observations in which both sex and gonad condition were recorded.

[2] The presence of milt in the testes does not necessarily indicate advanced maturity, as male albacore taken in tropical and subtropical waters almost invariably contain some milt in testes regardless of the degree of sexual maturity.

who examined histologically a series of male and female gonads, concluded that the British Columbia fishery is dependent on immature fish. Brock (1943) recorded a range in egg diameter 0.01 to 0.1 mm. in Oregon albacore. He repor that "fish with ripening ova are not present the Oregon fishery and have never been recor from the California fishery." Kishinouye (19 found no fish with maturing reproductive eleme in Japanese waters. According to Suda (195 albacore captured west of Midway Islands, no of the Subtropical Convergence, are all extrem immature, with gonad weights below 50 grams both males and females. Thus, the albac resource which furnishes the basis for the spr live-bait fishery in Japanese coastal waters the Japanese winter longline fishery in midoce as well as the American west coast fishery in summer, is composed either of sexually immat fish, or of adult fish which show no signs of go development beyond the early developing st The implications are, therefore, that albacore not spawn in the temperate waters of the No Pacific.

HAWAIIAN ISLANDS

Because of the great predominance of males the landings of albacore in the Hawaiian Isla (fig. 7), coupled with the small numbers tak we had hoped initially to utilize both male female gonads in this study. We found, howev that the presence or absence of milt is no

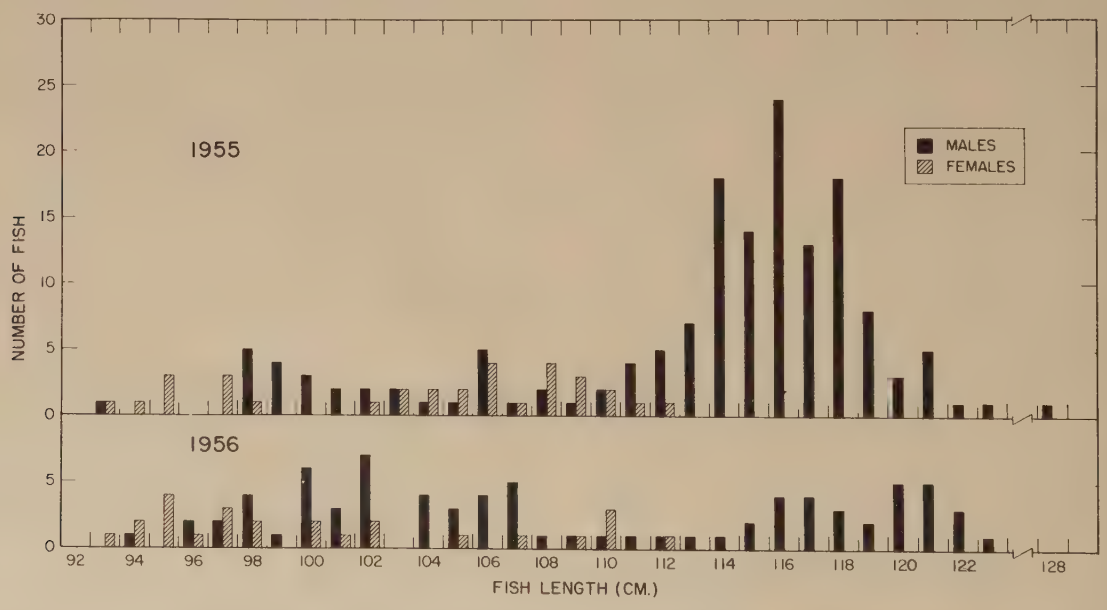


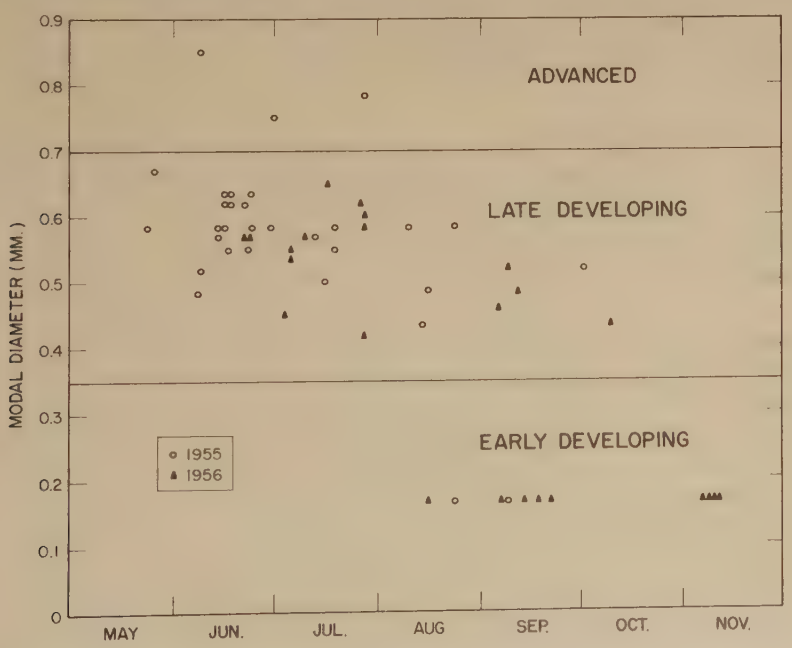
FIGURE 7.—Size and sex distribution of albacore sampled from landings in the Hawaiian Islands, (a) 1955 (b) 195

nitive measure of maturity, since regardless of ir size, the testes of albacore in Hawaii invari- y contain some milt. It was decided, there- , that only the ovaries would be used for the dy of sexual maturity of the Hawaiian and tral equatorial Pacific albacore.

Examination of the ovaries from 56 fish revealed ying degrees of maturity from early developing advanced. Eleven fish ranging in weight from to 59 pounds possessed early developing ries; 42 fish, ranging from 33 to 62 pounds, had developing ovaries; and 3 fish, of 41, 47, and pounds, contained advanced ovaries. The quency distributions of egg diameters for the late developing and 3 advanced ovaries, and 4 of the early developing ovaries are presented able 7. No measurements were made on the ainder of the early developing ovaries with the eption of noting their maximum egg diameters; e exceeded 0.23 mm. The data (table 7) are anged progressively from the early developing the most advanced ovaries as determined by position of the last mode. The modal diam- s indicated here were selected by eye after the a had been smoothed twice by a moving rage of three. Most of the ovaries showed istinct second mode which is also indicated.

The modal diameters of the most advanced eggs in each of the 56 ovaries of Hawaiian fish are shown in figure 8 by date of landing. The modal diameters of the 11 early developing ovaries are plotted arbitrarily at 0.167 mm. (10 micrometer units) although the true mode was considerably below this value; only eggs larger than 10 micrometer units were measured.

Of the 36 ovaries sampled in May, June, and July, 3 were advanced and 33 were in the late developing stage; none was in the early developing stage. In August and September, however, of 14 examined, only 7 were in the late developing stage; the remainder were early developing. In October and November, of 6 examined, only 2 were in the late developing stage and 4 were early developing. The above may be an indication that some spawning took place during the summer months. Although the 3 advanced ovaries were not fully ripe, the appearance of the eggs suggested that spawning was not far distant. Clark (1929) examined 21 albacore from Hawaiian waters during the summer of 1929 and reported that all of these fish were "practically mature and ready to spawn." On the other hand, it is possible that albacore have a protracted spawning season, and that the apparent summer spawning season in Hawaii merely reflects seasonality in their occurrence in these waters (table 1).



URE 8.—Modal diameter of the most advanced group of eggs shown by date of landing for each of the 56 albacore from Hawaiian waters.

TABLE 7.—*Frequencies of egg diameters, in micrometer units (upper figu*

[Asterisks mark modal diameters]

Ovary number	10 .167	11 .184	12 .200	13 .217	14 .234	15 .250	16 .267	17 .284	18 .301	19 .317	20 .334	21 .351	22 .367	23 .384	24 .401	25 .418	26 .434	27 .451	28 .468	29 .484	30 .501	31 .518
200	175	119	119	65	38	23	5	4	2													
184	142	100	88	65	76	46	21	9	3													
318	57	37	26	27	14	15	8	7	8	1												
290	60	36	29	15	15	14	8	5	4	8	3	1	1	1								
276	125	79	65	52	52	35	24	16	10	10	12	2	2	9	12	*12	5	6	7	6	3	2
353	32	15	15	9	4	10	12	7	8	7	3	3	5	5	8	10	*16	11	9	3	4	4
179	114	61	46	38	39	31	22	20	19	17	6	6	12	8	12	11	*12	16	10	8	6	5
264	105	66	38	39	40	39	24	24	18	29	12	10	13	13	6	8	10	*16	9	7	8	7
300	92	53	59	37	32	23	17	12	16	9	8	9	11	16	18	16	19	19	*24	19	18	13
32	64	31	25	35	25	30	18	21	16	14	12	11	5	19	11	15	16	21	21	*24	17	23
181	75	48	43	50	45	32	23	24	20	22	9	8	11	12	*22	18	14	7	13	*16	14	11
314	62	38	28	23	23	15	10	18	*22	14	12	13	12	25	14	16	15	23	34	*24	29	29
156	75	59	37	43	48	30	19	20	21	17	6	12	6	8	8	11	15	20	15	12	*24	12
41	58	36	31	22	12	14	24	*23	11	16	15	14	14	10	8	10	23	26	24	28	24	*36
305	85	48	37	33	33	22	11	13	18	12	8	20	*12	18	9	10	3	5	18	14	16	*24
209	43	24	18	15	15	11	19	19	8	12	14	15	9	8	6	17	18	30	31	30	34	*50
256	66	35	31	31	27	20	20	12	17	21	16	10	14	13	*13	20	9	13	15	14	16	30
257	57	31	33	38	39	22	18	20	32	16	15	9	10	16	11	8	7	7	11	12	7	11
88	46	41	30	25	18	18	17	13	11	14	16	19	*13	24	10	17	11	9	12	9	7	12
116	74	59	42	36	28	38	17	15	16	13	15	10	4	15	13	11	10	4	8	9	6	16
159	71	45	35	30	31	36	11	25	22	24	18	13	17	20	11	10	5	8	14	7	9	9
251	72	42	27	28	27	24	19	18	23	23	14	13	13	*20	19	15	9	12	12	7	8	8
246	62	38	25	24	21	26	12	16	24	22	11	7	10	20	*23	20	10	13	16	11	8	11
259	62	30	26	21	12	20	19	19	30	17	10	11	14	14	14	*23	13	9	16	11	13	17
153	215	151	167	154	161	137	98	88	88	93	82	50	60	69	78	*87	56	67	38	41	25	34
74	259	137	124	117	107	115	82	72	75	69	51	48	54	*56	45	59	40	39	47	29	32	16
185	77	44	37	30	27	33	22	15	16	15	10	7	11	13	10	14	8	16	8	11	16	10
158	35	24	22	23	25	26	18	22	23	19	12	19	16	22	*17	24	9	11	6	4	14	11
275	87	43	39	30	36	29	14	17	16	15	13	9	13	12	*22	15	17	13	10	1	10	4
130	86	54	40	35	30	21	21	17	16	10	12	11	11	8	*13	14	8	10	7	8	7	5
79	76	55	42	36	36	29	22	12	17	21	12	9	9	14	*14	12	8	8	8	7	9	8
75	87	57	46	37	29	26	21	18	22	13	8	9	13	*14	9	11	9	8	7	5	2	8
80	105	51	34	38	39	40	27	29	27	17	13	13	15	14	*22	15	15	8	8	8	10	4
122	53	33	22	21	33	19	15	19	19	18	15	10	14	19	*21	22	11	16	10	7	7	4
174	61	37	23	26	22	40	20	17	19	23	17	13	19	9	15	*22	9	21	11	10	10	4
15	81	30	32	27	18	36	15	15	30	13	21	10	12	16	13	*22	13	9	17	6	6	1
277	102	54	40	40	34	29	15	17	15	15	12	13	6	12	10	*14	6	9	15	7	10	7
274	82	44	36	29	23	23	18	17	16	14	12	6	6	9	8	14	*7	8	13	8	9	7
110	61	30	36	18	27	40	14	23	13	17	21	16	14	11	15	*21	14	8	16	9	9	4
91	49	28	32	25	22	31	20	22	23	18	16	14	15	18	20	*15	6	17	14	13	15	5
82	87	37	34	35	27	29	21	18	23	18	18	14	16	12	10	*17	14	13	11	7	7	3
123	67	35	31	31	24	21	19	14	18	17	12	9	12	18	9	19	*13	14	22	7	3	1
84	72	40	33	25	22	24	17	15	25	13	12	9	13	17	20	*20	16	13	20	11	9	11
90	44	32	25	32	27	27	25	14	19	11	17	8	10	21	*16	21	8	16	19	12	12	4
269	32	22	24	25	11	17	21	21	12	11	16	7	12	19	15	*33	24	15	13	13	1	6
18	61	41	28	29	31	27	11	24	20	11	12	9	5	13	15	*16	12	16	13	4	10	0
145	189	94	83	85	74	93	52	61	66	46	44	36	38	47	40	49	42	*53	47	24	13	4
165	86	63	54	41	44	37	31	28	29	26	15	4	12	13	13	*15	10	12	12	8	6	6
42	104	58	28	29	16	23	10	8	18	15	17	12	10	9	10	9	8	10	12	4	7	4

[1] No measurements were made on 7 of the 11 early developing ovaries with the exception of noting the maximum egg diameters; none exceeded 0.22

CENTRAL EQUATORIAL PACIFIC

While the vast region of the tropical Pacific is here treated as a single unit because of the small amount of data available, it is realized that a more detailed study of smaller units of area would be desirable.

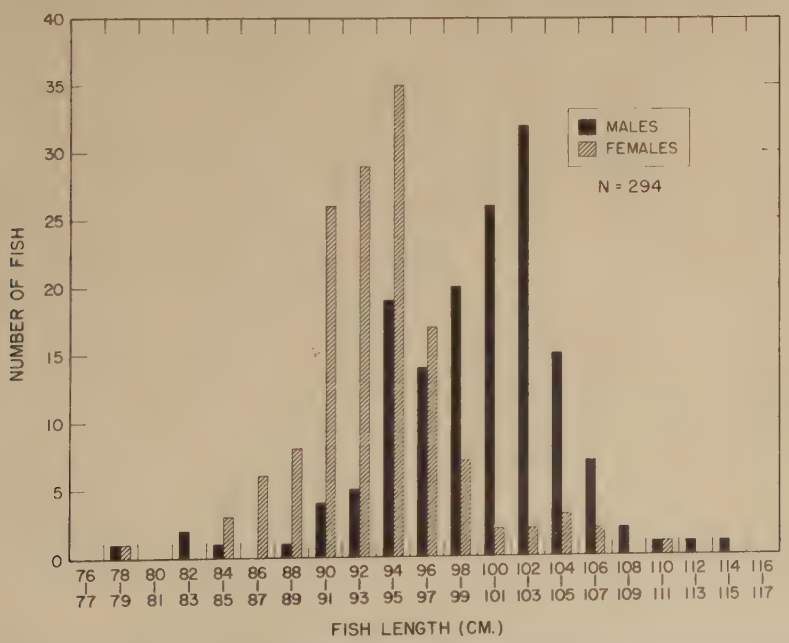
The albacore caught in the equatorial Pacific (fig. 9) were intermediate in size between those from the North Pacific and those from Hawaii. If only the female fish are considered, however, their sizes were not much smaller than the female fish sampled from Hawaiian waters. One notable difference was in the sex ratio, which in this region was nearly 1:1, while in Hawaiian waters the males predominated (fig. 7).

Ovaries from 66 fish were examined. Of this total, 54 were in the early developing and 12 were in the late developing stage (table 8). figure 10 the maximum egg diameter of eac the 66 ovaries is shown by date of capture of fish. Maximum egg diameter was used, bec no other measurements were made on mos the early developing ovaries. Most of the s ples were collected during February and Nov ber 1952, in February and May 1953, Septe 1956, and January and February 1957. S late developing ovaries were found during a these periods with the exception of February 1 The areas from which late developing ov were obtained are also indicated in figure 1. T appear to be randomly scattered. It is evi that no conclusions can be drawn from the am of data available regarding the spawning and locality.

mm. (lower figure), for ovaries from the Hawaiian Islands [1]

[Asterisks mark modal diameters]

34 .568	35 .584	36 .601	37 .618	38 .635	39 .651	40 .668	41 .685	42 .701	43 .718	44 .735	45 .752	46 .768	47 .785	48 .802	49 .818	50 .835	51 .852	52 .868	53 .885	54 .902	55 .918	56 .935	57 .952	58 .969	59 .985	Sum
																										550
																										550
																										200
2																										200
																										550
4	1																									200
1																										531
0	2	1																								550
8	13	7	8	2	1	0	2																			550
1	2	1																								550
8	5	2																								550
6	1	1	1																							550
6	5	4	3	2																						550
15	12	4	4	4	1																					550
12	12	9	4	1	1																					550
12	15	4	0	3																						550
26	19	11	10	3	2																					550
28	25	16	9	10	6	2	3																			550
17	19	5	4	1	2																					550
13	16	7	6	6	3	1	1																			550
*16	16	7	10	11	6	4	2																			550
*25	25	18	8	5	2	1																				550
*17	23	20	10	8	3	2	1	1	2																	550
*69	67	53	21	9	4	0	1																			2, 391
*27	27	18	20	19	10	6	2	3	1																	1, 847
*17	16	12	10	10	4	4	1																			550
*27	33	17	12	8	5	2	0	1																		550
9	*19	12	14	6	5	4	2																			550
13	*21	13	17	9	7	3	1	1	1																	550
10	*10	15	11	4	4	4	1	1	1																	550
15	*21	12	9	4	3	2	1																			550
15	*14	10	6	9	7	2	2	1																		634
20	*25	21	21	17	8	4	3																			550
13	*24	14	15	8	6	6	3																			550
13	*24	16	14	6	4	2	3	1																		550
3	10	*7	8	8	5	6	3	1	3	0	1	0	1													550
8	15	21	*25	21	13	8	6	4	2																	550
9	11	10	*25	7	11	11	7	7	6	0	2															550
9	9	8	*19	11	8	13	5	6	1	0	0	0	1													550
8	9	6	*15	14	13	3	1	3	1	1																550
10	15	17	17	*26	14	14	6	4	2																	550
2	1	9	7	*12	6	8	8	9	10	4	1	3	1	1	2											550
8	11	12	14	*22	9	21	11	7	3	1	1	0	1													550
10	10	20	16	27	*31	19	17	10	5	1	2	1														550
2	2	4	11	18	15	*21	15	11	15	7	10	0	3	1	1											550
4	7	3	11	11	13	15	11	16	23	24	*30	24	28	22	11	10	4	5	2	3	1	1	0	1		1, 568
2	0	1	0	1	1	1	2	6	5	5	5	7	*9	6	5	5	5	6	4	3	2	1	2			656
1	2	1	0	0	0	1	0	0	1	1	1	1	11	6	6	16	*9	10	15	2	12	7	5	0	2	550



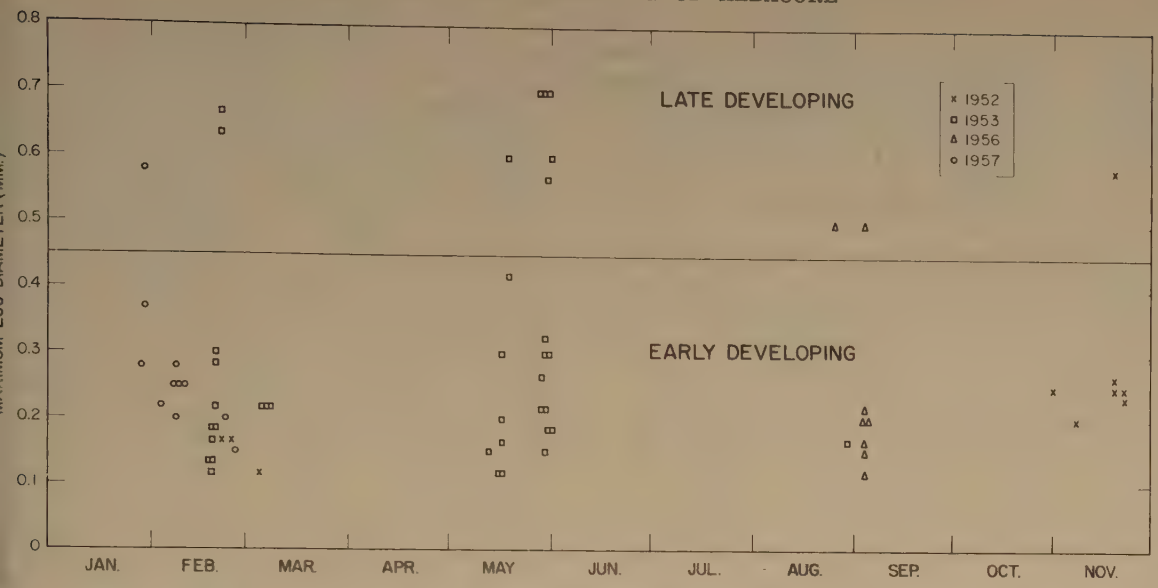
RE 9.—Size distribution, by sex, of central equatorial Pacific albacore captured during the years 1952 to 1957, and for which sex and size data were recorded.

TABLE 8.– *Frequencies of egg diameters, in micrometer units (upper figure) and mm. (lower figure), for ovaries from the central equatorial Pacific Ocean* [1]

[Asterisks mark modal diameters]

Ovary number	10 .167	11 .184	12 .200	13 .217	14 .234	15 .250	16 .267	17 .284	18 .301	19 .317	20 .334	21 .351	22 .367	23 .384	24 .401	25 .418	26 .434	27 .451	28 .468	29 .484	30 .501	31 .518	32 .534	33 .551	34 .568	35 .584	36 .601	37 .618	38 .635	39 .651	40 .668	41 .685	42 .701	Sum
C–16	126	82	72	53	36	37	27	31	28	17	13	13	10	2	2	1																		550
C–49	39	23	16	20	18	7	18	13	5	5	*11	4	3	5	3	2	3	1	0	3	1													200
C–48	26	13	11	9	8	17	13	13	3	3	15	*10	10	7	8	8	10	4	5	4	3													200
C–3	57	42	35	22	28	33	30	14	18	16	14	18	19	20	22	*28	27	18	15	14	12	12	9	10	5	6	1	3	2					550
C–42	94	48	41	33	27	30	22	21	17	20	20	23	24	19	18	*24	27	12	15	5	4	3	0	0	2	0	1							550
C–20	67	39	38	22	23	19	16	*30	24	20	17	16	20	22	12	32	*21	27	27	10	18	14	7	6	2	1								550
C–31	126	77	57	31	19	20	13	8	10	3	6	12	9	12	12	13	20	*22	22	12	10	13	12	6	0	2	3							550
C–10	119	75	58	54	36	31	11	22	16	11	12	5	14	15	8	9	10	11	*16	7	2	3	2	2	1									550
C–61	61	35	30	29	32	30	25	23	24	15	22	20	19	19	13	18	23	22	*23	26	20	10	8	2	1									550
C–37	72	44	44	36	17	23	23	24	19	17	12	9	15	15	7	16	21	21	*20	20	16	8	9	9	12	8	3	3	3	3	0	0	1	550
C–1	58	28	25	19	15	14	14	15	14	20	20	16	16	17	22	15	20	22	16	18	26	*23	22	24	18	15	9	5	3	0	1			550
C–13	117	86	81	49	34	21	21	20	14	12	8	8	4	2	0	3	7	5	9	6	9	*13	3	4	5	5	1	1	1	0	0	0	1	550
C–2	96	56	36	25	23	20	11	20	12	10	15	11	10	11	9	12	17	16	19	11	16	*19	15	13	11	9	8	6	7	2	1	2	1	550

[1] Eggs from only one early developing ovary (albacore No. C–16) were measured.



GE 10.—Maximum egg diameter for each of the 66 central equatorial Pacific albacore by date of capture. (Since nly the maximum egg diameter was recorded for most of the early developing ovaries, this measurement rather nan the modal diameter is used.)

EVIDENCE OF SPAWNING

e spawned-out or spent stage is recognized ne presence of remnants of ripe eggs (residual in the process of resorption) in the lumen of vary (Schaefer and Orange, 1956; Yuen and , 1957). A fresh, unpreserved spent ovary is ally hollow and flaccid. In preserved speci-, however, it may resemble any of the other s of maturity, even the early developing , depending upon how recently spawning ccurred. Egg remnants were actually found aries in all stages of maturity from early oping through advanced.

this study we classified the ovaries into opmental stages without regard to the pres- or absence of egg remnants. In figure 11 naximum egg diameter for each of the Hawai- nd central equatorial Pacific albacore is shown sh size, and the ovaries which contained egg ants are indicated. No distinction was made e quantity of remnants in the ovaries, nor of stage of resorption. While the absence of emnants may not be accepted as proof that ish has never spawned, their presence con- es good evidence that spawning has oc- d (June 1953; Yuen 1955; Schaefer and ge, 1956; Yuen and June, 1957). Of a total of awaii samples, 47 contained egg remnants, ating that these fish had spawned. Similarly central equatorial Pacific ovaries examined,

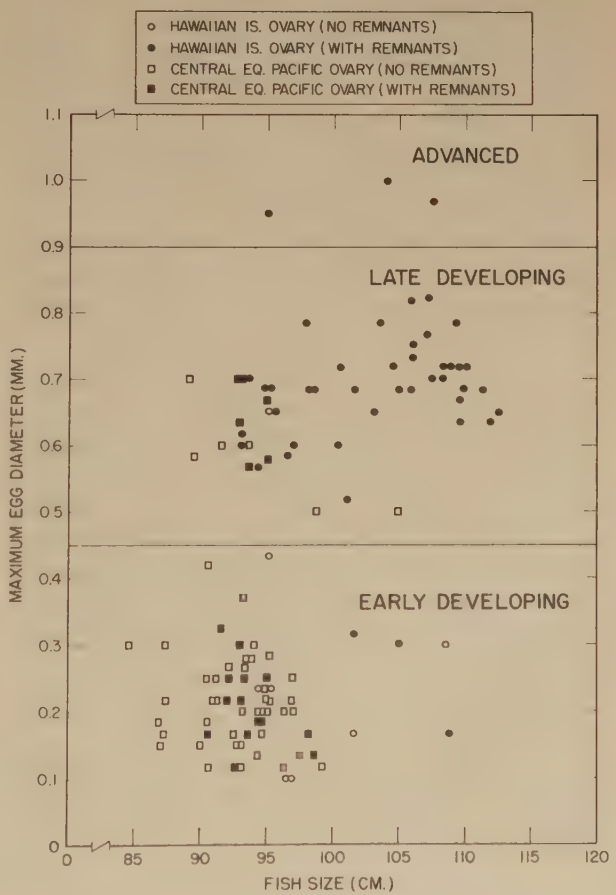


FIGURE 11.—Relation between fish size and maximum egg diameter. Ovaries with egg remnants are indicated.

20 contained egg remnants. None were found in the North Pacific ovaries, thus giving added weight to the conclusion that spawning does not occur in the North Pacific.

MINIMUM SIZE OF SPAWNING FISH

Ueyanagi (1955) has inferred from his studies that the albacore attains sexual maturity and may spawn at about 90 centimeters in length. Our observations are in agreement with this.

The 12 central equatorial Pacific ovaries in the late developing stage were obtained from fish ranging in length from 89.1 cm. to 104.8 cm. (weight, 33 to 54 lbs.); the 45 late developing and advanced ovaries from the Hawaiian area were taken from fish larger than 93.1 cm. (33 lbs.). Additional evidence regarding the minimum size at spawning can be found in figure 11. Although egg remnants were present in ovaries at all stages of maturity, none were found in fish less than 90 cm. in length. Therefore, our data suggest that the albacore attains sexual maturity at a size of about 90 cm. (33 lbs.), which coincides with Ueyanagi's findings.

FREQUENCY OF SPAWNING

The frequency distributions of egg diameters (figs. 5 and 6, tables 7 and 8) show clearly two or more modes which, depending on the growth rate of the egg, may represent eggs that will be spawned in a single season or in succeeding seasons. As the data do not permit determination of the growth rate of eggs, reference is again made to figure 11. The fact that the three advanced ovaries as well as most of the late developing ovaries contained egg remnants strongly indicates that the albacore undergoes multiple spawning. The lack of remnants in large, sexually inactive adults taken during late winter in the North Pacific suggests that remnants are not carried over from one year to the next, though in the absence of any knowledge regarding the rate of resorption of the unspawned eggs, no definite conclusions can be drawn. The presence of egg remnants together with a group of eggs approaching ripeness suggest, however, that albacore may spawn at least twice during a single spawning season.

FECUNDITY

Fecundity calculations were based on assumption that all of the eggs comprising most advanced group within an ovary w released in a single spawning. Eight Hawa fish of varying sizes were selected for this stu From each pair of ovaries, a random sample obtained; this was weighed to the nearest 0. gram. All of the eggs comprising the m advanced group within the sample were t counted. The total number of such eggs in pair of ovaries was estimated by multiplying number in the sample by the ratio of ova weight to sample-weight. The results are sho in table 9. The data are arranged in the orde increasing fish size from 36 to 62 pounds. addition, two calculations made by Ueyan (1955) are included.

TABLE 9.—*Estimations of the number of eggs in the advanced group in the ovaries*

Albacore No.	Body wt. (lbs.)	Ovary wt. (gms.)	Sample wt. (gms.)	Number of mature eggs in sample	Estim numb mat eggs ova (milli
158	36	183	0.1215	579	
75	39	271	.1862	882	
275	41	319	.1435	418	
42	47	538	.2367	482	
74	54	513	.0560	513	
84	57	552	.1983	582	
145	60	916	.1197	238	
153	62	194	.0811	411	
A [1]	50	365	.2		
B [1]	53	613	.2		1

[1] From Ueyanagi (1955).

There appears to be a slight tendency larger fish to have more eggs per spawning bu is not as definite as that found for the yello (June 1953) and bigeye tuna (Yuen 1955). estimated total numbers of eggs in the m advanced group were remarkably uniform, ra ing between 0.9 and 1.8 million eggs per indivi female. Including Ueyanagi's estimates, the ra is from 0.9 to 2.1 million eggs.

OVARY SIZE AS INDEX OF MATURI

While the state of maturity of an ovary can determined reliably by means of egg diam measurements, a more simple and yet objec

iod for making rapid field determinations is able. The size of the ovaries, if directly ed to maturity, should provide a reasonable rion. Our data show that all of the early loping ovaries from the central equatorial fic weighed less than 100 grams, and that developing ovaries ranged from 104 to 363 is. The early developing ovaries from the aiian area, however, ranged in weight from 179 grams, the late developing ovaries from o 805 grams, and the three advanced ovaries hed 181, 538, and 916 grams, respectively. , while the ovaries from the central equatorial fic fall conveniently into two stages of rity according to their weights, there is iderable overlap in the Hawaiian samples. pears, therefore, that ovary size is actually a criterion to follow in assessing the state of rity of an ovary.

ecently, the relative ovary weight (ovary ht $\times 10^3$/fish weight) has been found to be rly reliable measure of maturity for Hawaiian wfin (June 1953) and central Pacific bigeye (Yuen 1955). This relation was therefore d for the albacore ovaries. In figure 12 the rel- ovary weight of each of the Hawaiian and central equatorial Pacific albacore is plotted against the maximum egg diameter. Here again, the data do not permit the use of modal diameters, for these were not determined for most of the early developing ovaries. The data presented in tables 7 and 8 indicate an acceptable correlation between modal and maximum diameters which justifies the use of the latter. The early developing ovaries, with only one exception, have relative ovary weights of less than 6, while all but three of the late developing ovaries have relative ovary weights greater than 6. Thus, with a reasonable amount of confidence, a relative ovary weight of 6 may be considered as the value which separates the early developing from late developing ovaries.

The late developing ovaries ranged in relative ovary weight from 6 to 30 with a general tendency for the ratio to increase with progressing maturity. The three advanced ovaries, however, failed to conform to any pattern and varied in relative ovary weights from 10 to 34. Despite the large variation exhibited by the three ovaries in the advanced stage, the data in general point to a definite relation between relative ovary weight and the state of gonad development.

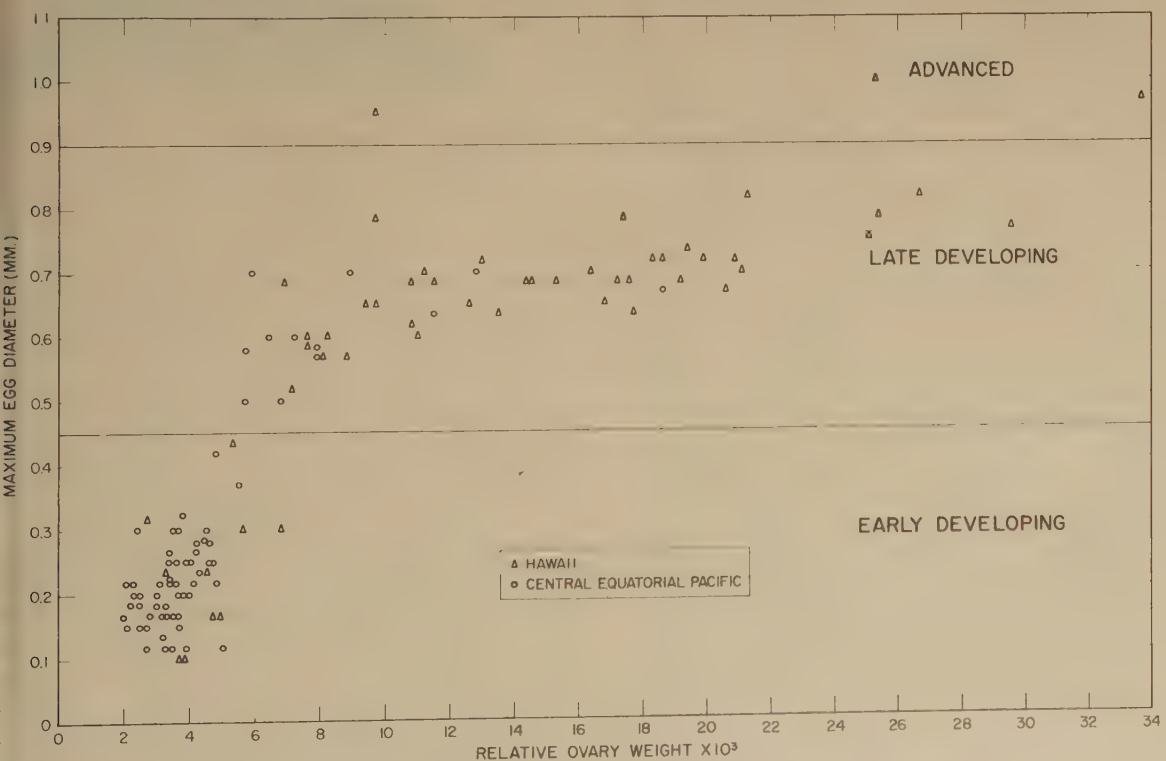


FIGURE 12.—Relation between relative ovary weight and state of maturity.

DISCUSSION

Our samples did not include any ovaries that were fully ripe. Three ovaries were classified as "advanced" on the basis of the appearance of the eggs. Although they were advanced in maturity, and presumably close to spawning, it has not been possible to determine the time required for these ovaries to attain a fully ripe stage. Because these advanced ovaries were collected during the summer months, and since a large percentage of ovaries collected in the fall were in the early developing stage (fig. 8), it was postulated that some spawning occurs during the summer in the vicinity of the Hawaiian Islands.

Fully ripe fish apparently are not available to the fishery. June (1953), working with Hawaiian yellowfin, concluded that this species spawns in Hawaiian waters. He found only one fully ripe ovary among his samples, however, and stated that "fish that are actually spawning either do not take the hook or migrate into deeper water outside the longlining grounds." Similarly, Schaefer and Orange (1956) stated that "apparently, when the yellowfin tuna imminently approach spawning, they become unavailable to the fishery." This behavior was noted earlier by Schaefer (1948) for yellowfin tuna and skipjack off Central America. Brock (1954) also found that fully ripe skipjack are not commonly available to the Hawaiian skipjack fishery. Thus, the possibility that fully ripe tunas are generally unavailable to the fishery may be one reason for the small number of advanced ovaries and the complete absence of ripe ovaries in our collections.

Most of the ovaries examined from the central equatorial Pacific were in the early developing stage, but a few late developing ovaries were present as well as those that contained relics of past spawning. Absence of advanced stages may mean that these fish do not spawn in this region. Unfortunately, not much is known of the maturity of the albacore taken in other regions of the tropical Pacific. Some field observations on the gonads of albacore landed by the Japanese tuna mothership expeditions between April and September of 1951 are available for the western equatorial Pacific between the Equator and 6° N. latitude and between 144° E. and 174° E. longitude (general vicinity of the Caroline and Marshall Islands). Descriptions of these expeditions are given by Shimada (1951), Ego and Otsu (1952), and Van Campen (1952). Of a total of observations made by observers from PC during this period, 33 were recorded as immatu 6 as spent, and only 2 as mature. Judging fr these records, it may be assumed that the matur of the western Pacific albacore during this per more nearly resembled that of the central equ torial Pacific albacore than that of the Hawai fish.

Ishii and Inoue (1956) postulated that the Co Sea and adjacent New Caledonia area w spawning areas for the albacore. Their study w based on only two ovaries which, according their descriptions, corresponded to our ea developing and late developing stages. On t basis of these data, it is surmised that the matur of the fish in this area is much like that fou throughout the central and western equato

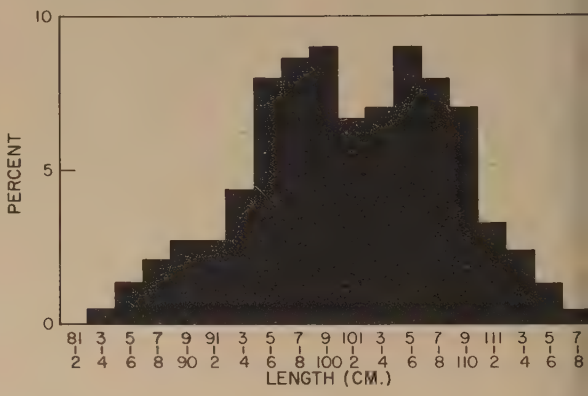


FIGURE 13.—Length composition of Indian Ocean alba (reproduced from Ueyanagi 1955, fig. 2).

Pacific. It is interesting to note that Ueyan (1955) reported on two well-advanced ova obtained in February 1953 from the south waters of Sunda Islands (Indian Ocean); one the ovaries he referred to as "ripe" and the ot as "nearly ripe".[2] He has hypothesized that albacore which occur in the Indian Ocean spa in February, at least, in part. He believes t the area from south of the Sunda Chain to nor west of Australia may be the spawning grounds the Indian Ocean albacore, since the fish tal there are generally large. Ueyanagi's size-f quency data of the Indian Ocean albacore (fig.

[2] Ueyanagi very kindly sent us samples taken from these two ov The sample he referred to as "nearly ripe" corresponds in maturity t developing ovaries, and the "ripe" to one of the advanced ovaries i present study.

ely resemble that of the central equatorial ific albacore (fig. 9).

he best indications of albacore spawning are efore available from two widely separated lities, the Hawaiian Islands in the central ific and Sunda Islands in the Indian Ocean, former during the northern summer and the er during the southern summer.

is not known whether the albacore appearing arious parts of the Pacific Ocean belong to a le intermingling population or whether there discrete populations in the various areas. a (1956) is of the belief that the albacore occur- in the North Pacific Current area are a ding group" and that there is a corresponding awning group" in the North Equatorial Current Furthermore, he postulates that the alba- of the Indian Ocean as well as the tropical h Pacific comprise the spawning group of her feeding group located in South Pacific perate waters. If this is indeed the case, it be that the Hawaiian Islands represent a ion of the spawning grounds of the northern ilation, and that the Sunda Islands, that of southern population.

ur data suggest that albacore attain sexual urity at about 90 centimeters in length ght, 33 lbs.). This signifies that the fish oited during the spring and summer by the anese and the Americans in the temperate ers of the North Pacific are largely sexually ature fish (Suda 1955, Brock 1943). The anese winter longline fishery in the North fic, on the other hand, exploits both juvenile adult fish (Suda 1954). The gonads of these t fish do not show any development, however. situation is in contrast to that in the Ha- an Islands where the catch is wholly of adult (fig. 7). Many of these have gonads showing iderable development. In the central equa- l Pacific, the fish are also generally large and are adults with gonad development inter- iate between North Pacific and Hawaiian ds fish. It appears possible that the Ha- an and central equatorial Pacific albacore are gment of the population which, after attaining rtain size in temperate waters of the North fic, moves south into tropical and subtropical rs to reproduce.

SUMMARY

1. This study is based on examination of gonads of albacore taken from three general areas: the North Pacific (north of 30° N. latitude, between 180° longitude and the west coast of the United States), the Hawaiian Islands, and the central equatorial Pacific (Equator to 12° S. latitude, between 180° and 150° W. longitude, with scattered samples collected from as far east as 120° W.). Although the three areas are treated separately throughout this report, this does not infer that the fish belonged to separate stocks, or populations.

2. Gonads of both sexes were used in the study of the maturity of North Pacific albacore. Only the ovaries were used for the other two areas and the degree of maturity was determined largely from egg diameter measurements.

3. The several tests made to determine the most efficient sampling procedure indicated that mature eggs were randomly distributed throughout the length of an ovary but there were some differences in the transverse distribution. There were no differences in the distribution between the two ovaries of a pair. The adopted method of sampling was to take a random sample from the mid-section of an ovary.

4. The ovaries were classified in three stages of relative maturity: early developing, late developing, and advanced, on the basis of the most advanced eggs present. The advanced ovaries were not in a fully ripe condition.

5. The North Pacific albacore were either juveniles or sexually dormant adults with early developing gonads.

6. The Hawaiian albacore evinced varying degrees of maturity from early developing to advanced, with the bulk of the ovaries in the late developing stage. Although the samples were somewhat inadequate for a conclusive study, there was indication that spawning may occur during the summer months in the vicinity of the Hawaiian Islands. The data also indicated the possibility of a somewhat protracted spawning season.

7. The ovaries from central equatorial Pacific fish were in the early developing and late developing stages, with the early developing stage predominating.

8. The presence of egg remnants in the ovaries indicated that most of the Hawaiian fish had spawned previously. None of the ovaries from the North Pacific contained egg remnants. Of 66 central equatorial Pacific ovaries, 20 contained egg remnants. Remnants of eggs were present in ovaries in all stages of maturity from early developing through advanced.

9. The minimum size at which albacore attain sexual maturity and participate in spawning appears to be about 90 cm. (weight, 33 lbs.).

10. The size distribution of eggs within an ovary, as well as the frequent occurrences of egg remnants in advanced and late developing ovaries, indicate that albacore may undergo at least two spawnings during a spawning season.

11. Assuming that all of the eggs comprising the most advanced group within an ovary are extruded in a single spawning, the number released per spawning is about 1 to 2 million eggs per individual female albacore.

12. Ovary size is not a reliable criterion to follow in assessing the degree of maturity of an ovary. Relative ovary weight (ovary weight $\times 10^3$/virgule fish weight) is shown to be the more reliable index, particularly for segregating early developing from late developing ovaries.

13. This study shows that albacore caught by POFI vessels north of Hawaii, as well as those taken by the Japanese spring live-bait and winter longline fisheries, and those supporting the American west coast summer fishery are non-spawning fish that are either juveniles or adult fish whose gonads give no signs of incipient or past spawning. Albacore apparently do not spawn in the temperate waters of the North Pacific.

14. It appears possible that the albacore in region of the Hawaiian Islands and in the central equatorial Pacific represent a segment of the population which, after attaining a certain size in temperate waters of the North Pacific, moves south into tropical and subtropical waters to reproduce.

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U. S. GOVERNMENT PRINTING OFFICE: 1959 O - 485320

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STUDY OF AGE DETERMINATION BY HARD PARTS OF ALBACORE FROM CENTRAL NORTH PACIFIC AND HAWAIIAN WATERS

BY TAMIO OTSU AND RICHARD N. UCHIDA

FISHERY BULLETIN 150

From Fishery Bulletin of the Fish and Wildlife Service

VOLUME 59

UNITED STATES DEPARTMENT OF THE INTERIOR

FISH AND WILDLIFE SERVICE

UNITED STATES DEPARTMENT OF THE INTERIOR, Fred A. Seaton, *Secretary*
FISH AND WILDLIFE SERVICE, Arnie J. Suomela, *Commissioner*

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UNITED STATES GOVERNMENT PRINTING OFFICE • WASHINGTON • 1959

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price 15 cents

Library of Congress catalog card for this bulletin:

Otsu, Tamio.

Study of age determination by hard parts of albacore from central north Pacific and Hawaiian waters, by Tamio Otsu and Richard N. Uchida. Washington, U. S. Fish and Wildlife Service, 1959.

iv, 353–363 p. illus., diagrs., tables. 26 cm. (U. S. Fish and Wildlife Service. Fishery bulletin 150)

"From Fishery bulletin of the Fish and Wildlife Service, volume 59."

Bibliography: p. 363.

1. Tuna fish. I. Uchida, Richard N., joint author. (Series: U. S. Fish and Wildlife Service. Fishery bulletin, v. 59, no. 150)

[SH11.A25 vol. 59, no. 150] Int 59–17

U. S. Dept. of the Interior. Library
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Library of Congress catalog card for the series, Fishery Bulletin of the Fish and Wildlife Service:

U. S. *Fish and Wildlife Service.*
Fishery bulletin. v. 1–
Washington, U. S. Govt. Print. Off., 1881–19

v. in illus., maps (part fold.) 23–28 cm.

Some vols. issued in the congressional series as Senate or House documents.
Bulletins composing v. 47– also numbered 1–
Title varies: v. 1–49, Bulletin.
Vols. 1–49 issued by Bureau of Fisheries (called Fish Commission, v. 1–23)

1. Fisheries—U. S. 2. Fish-culture—U. S. I. Title.

SH11.A25 639.206173 9–35239 rev 2*

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ABSTRACT

Various hard parts of large (93–128 cm.) albacore, *Germo alalunga* (Bonnaterre), from Hawaiian waters and smaller fish (50–112 cm.) from the central North Pacific were examined for marks that could be used in determining age in this species. A cursory examination of the opercular bones and fin spines revealed no usable marks. A study of scale samples from 100 albacore showed that only one-half of them were readable, and these only with a considerable degree of subjectivity.

Several workers in other areas have reported apparent success in aging albacore by means of the rings on the vertebral centra. Their results could not be duplicated in the present study. In attempts to read the rings in the vertebrae of 212 Hawaiian and 53 central North Pacific albacore, the authors found little agreement between the counts of the different readers or even between successive counts by the same reader. Indications were seen that the rings on the vertebrae are not annuli but rather that they may be growth marks laid down randomly with time. As a clue to relative age, however, they may provide an explanation of the unbalanced sex ratio of large albacore, for they indicate the possibility that among mature fish the males grow faster than the females.

The results of this study, though largely negative, are presented for the information of those engaged at present in similar studies and for others who may work on this problem in the future.

UDY OF AGE DETERMINATION BY HARD PARTS OF ALBACORE FROM CENTRAL NORTH PACIFIC AND HAWAIIAN WATERS

By Tamio Otsu and Richard N. Uchida, *Fishery Research Biologists*, U. S. Bureau of Commercial Fisheries

s part of the research program of the Pacific anic Fishery Investigations (POFI), Fish and dlife Service, a study was initiated to determine age and growth of albacore, *Germo alalunga* nnaterre), occurring in the region of the vaiian Islands and in the central North Pacific. s study and other investigations of the albacore urces of the Pacific are conducted by POFI er Public Laws 329 (80th Congress) and 466 tonstall-Kennedy Act, 83d Congress).

everal workers have reported on the age and vth of albacore as determined from surface kings on the vertebral centra. Uno (1936a, b) king with albacore taken by pole-and-line ng in the waters east of Cape Nojima, Japan, le age determinations on 988 fish. Aikawa Kato (1938) reported on age determinations lbacore based on 10 large fish taken near way Island and 5 small fish taken off north- ern Japan. Partlo (1955) studied the age and vth of the eastern Pacific albacore, utilizing vertebrae of 531 fish taken in 1950 from off- è waters adjacent to California, Oregon, hington, and British Columbia. Finally, ieras (1955) reported on age determination of albacore taken off the coast of Galicia in hwestern Spain.

was our hope to extend these findings to ide central North Pacific albacore and the ptionally large fish occurring in the Hawaiian . We assumed that methods employed in r areas to determine the age of albacore d be successfully employed in this study. efforts in this respect were entirely unsuccess- however, as we were unable to verify or dupli- findings of the other workers. It was our lusion that the markings on albacore hard s, particularly on the vertebrae, are not true marks, and therefore, cannot be used in the g of these fish. The results of our study, gh largely negative, are presented here for information of those who are presently engaged in similar studies and for others who may work on this problem in the future.

E.—Approved for publication Jan. 16, 1958. Fishery Bulletin 150.

MATERIALS

Scales and vertebrae were routinely collected and certain other skeletal structures such as the operculum and the fin spines were also examined. Between January 1955 and July 1956, vertebrae and scales were collected from 212 albacore taken in Hawaiian waters and 53 from the central North Pacific.

Albacore taken by the Hawaiian longline fishery from an area within 20 miles of the main islands, were generally large, ranging in length from 93 to 128 cm. (weight, 33 to 93 lbs.) (fig. 1). These fish were sampled at the two Honolulu auction markets, the Hawaii Fishing Co., Ltd., and the United Fishing Agency, Ltd., where the landings of the Honolulu-based longline vessels were sold. Albacore were obtained from the central North Pacific on POFI's exploratory fishing cruises,

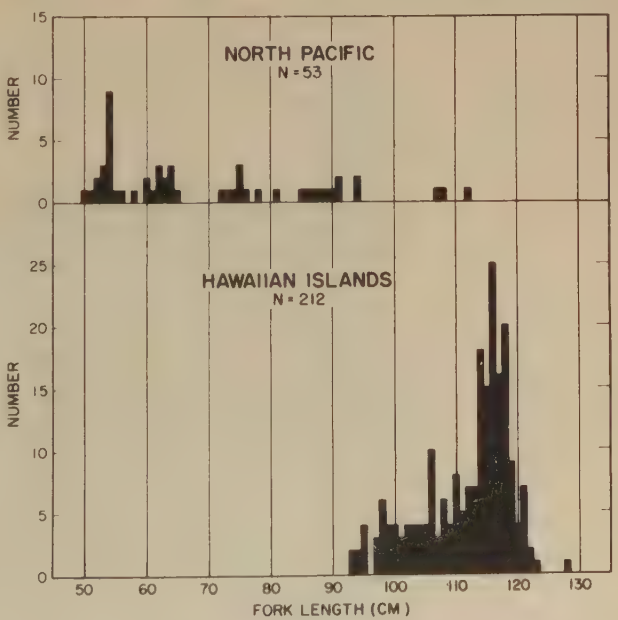


FIGURE 1.—Length frequency of albacore from which scales and vertebrae were collected.

which sampled an area between 140° W. and 180° longitude, from 30° to 50° N. latitude. These fish, taken by longline, trolling, and gill nets, were smaller, ranging in length between 50 and 112 cm. (6 to 65 lbs.) (fig. 1).

Scales were collected from the region of the body just below the second dorsal fin. The selection of this region was largely based on recommendations of researchers in California who were similarly engaged in the problem of aging the albacore, and who found scales from that region of the body "most promising" (personal correspondence). The 15th and 16th caudal vertebrae were selected for this study. While past investigators have used the thoracic vertebrae, our choice of the caudal vertebrae was based chiefly on accessibility, or the ease with which they could be acquired in the field or at the auction markets. This difference in the choice of vertebrae appears to be of little significance, since a careful examination of each of the 38 vertebrae of a single albacore revealed no notable differences in the appearance of the concentric markings.

METHODS

The scales were soaked in water overnight, after which the slime and adhering tissue were easily removed. The scales were then either dry-mounted between two glass slides or impressed on 0.030-inch thick cellulose acetate (1″ x 3″) strips, which were first softened by immers in 95-percent ethyl alcohol for 5 minutes.

Scale images were projected on a white pa screen with a microprojector. Because of variable sizes of the scales, the distance betw the projected image and the microprojector v varied so that approximately equal-sized ima could be produced. This tended to dimin to some extent the influence of the scale size making ring counts.

In processing the vertebrae for study, the section, cut off at or near the 5th dorsal fin was boiled in water until the flesh could eas be removed from the bone. After washing, vertebrae were sun-dried for about 2 days.

The method described by Partlo (1955) v followed in preparing the vertebrae for stu Where the 15th caudal vertebra was cut throu or damaged during collection, the 16th vertel was used. An electric jig saw was employed cut each vertebra along a sagittal pl slightly to one side of the median line. T larger of the resulting two parts was sanded do until the center of the centrum was clearly expo (fig. 2). Additional cleaning and accentuat of the concentric rings were done by immers the vertebra in a 1-percent solution of potassi hydroxide for about 48 hours, followed by rins in fresh water and preservation in 95 perc ethyl alcohol.

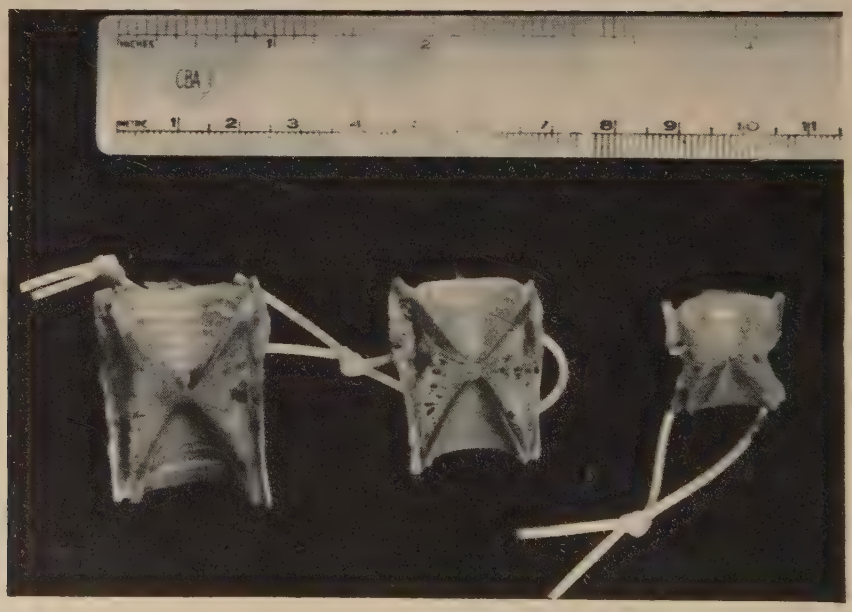


FIGURE 2.—Sectioned and prepared caudal vertebrae taken from albacore 113.9, 100.8, and 75.1 cm. long.

Measurements were made from the vertex of cone to each ring (ring radius) and also to outer margin of the cone (vertebral radius) ng the four exposed edges. Ring radii were sured with a pair of dividers under a dis- ing microscope and read off to the nearest mm. on a ruler graduated in 0.5-mm. intervals. anterior and posterior cone measurements e treated independently. The two corre- nding ring and vertebral radii measurements ach cone were averaged.

RESULTS

ous Skeletal Structures

ursory examination of the operculum, dorsal pectoral fin spines, and the hypural plate pro- ed no evidence that these structures possessed markings which could be interpreted as "age ks." The operculum showed distinct marks on the outer free edge; the central area was riably thickened and devoid of any markings.

es

he albacore scale is cycloid and either oval or hly rectangular in general outline. The circuli concentric with the margin of the scale. mination revealed that the smaller scales rally exhibited a rather distinct focus and ly defined circuli, but that the larger scales n fish larger than 90 cm.) were mostly charac- ed by obscure sculpturing and a thickened ral area. Furthermore, it was noted in several nces that scales from the same specimen ally in large fish) were of variable size and e. A count was made of the rings on different l scales from the same fish following the defini- of an annulus as given by Nose and others 5), who state: "The ring appears as a trans- nt line, near by which the circuli become fine discontinuous . . ." Though the counts on larger scales were necessarily somewhat sub- ve, because of the general opaqueness of the s, there appeared to be some trend in the ber of rings, the smaller scales having a lesser t than the larger. This would seem to indi- that the smaller scales had originated more tly than the larger ones.

lts of ring counts

ales from 100 fish were examined. Of this , the scales from 43 fish were considered unreadable, in large part because of opaqueness of the central area. The samples from the remaining 57 fish varied widely in the degree of readability. Despite the obvious difficulties, an attempt was made to count the rings on scales which had the greatest number of annuli for each sample. The ring counts are plotted against fish size in figure 3. There is a tendency for ring

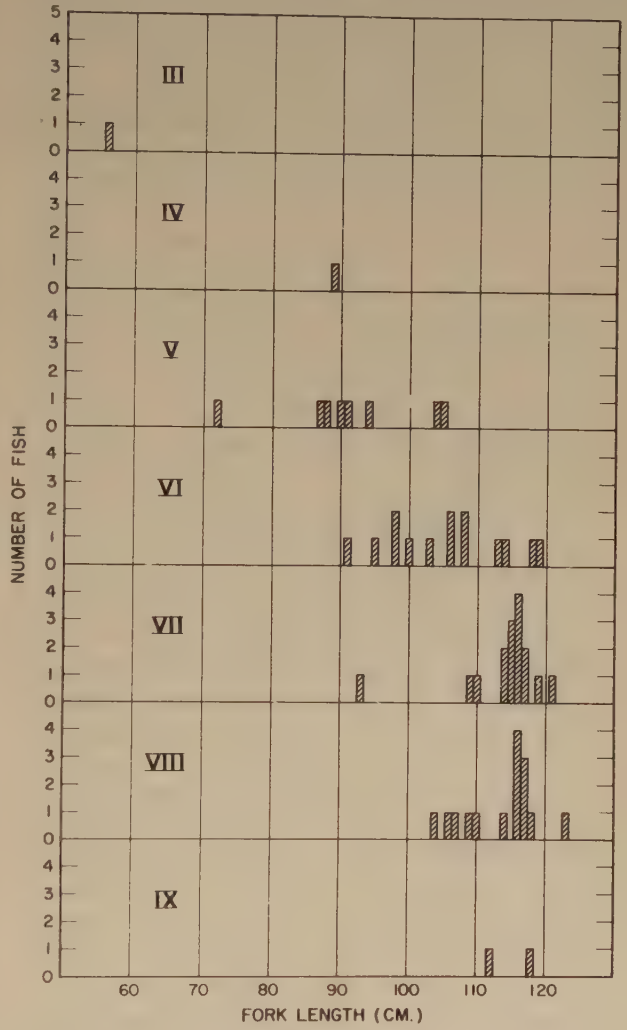


FIGURE 3.—Age of 57 albacore, determined by scale reading, plotted against fish size. (The Roman numerals represent the number of rings, or "age".)

counts to increase with increasing fish size, up to 8 rings. The size ranges of fish with 5 or more rings were broad, however, with a great amount of overlapping between successive groups.

Moore (1951) in working with Hawaiian yellowfin tuna encountered similar difficulties. He also

observed that small specimens of yellowfin, weighing about 5 pounds, had no scales except on the corselet region. He therefore concluded that scales were formed first on the anterior and later on the posterior part of the body. He stated that "if this is the case, any marks laid down in the scales would be of little value until the nature of scale formation and its relation with size and age of fish was known." The nature of scale formation on the albacore has not as yet been determined. Since it was our experience that only about half of the scales examined were considered readable, and these were read with considerable subjectivity, further work with scales was discontinued.

VERTEBRAE

Description

The albacore vertebra is amphicoelous, or concave at both ends of the centrum. A sectioned vertebra shows two cones, the vertices of which meet at or near the middle of the centrum, with their bases forming the margins of the vertebra. On the inner surface of these cones are concentric rings running parallel to the outer margin of the centrum. These rings are described by Partlo (1955) as "narrow translucent zones separated by broad, opaque zones similar to those described by Freidenfelt (1922) for *Lucioperca*. In the albacore the narrow zones were observed not only as translucent bands but also as eruptions or ridges on the centrum surface. The innermost ring differed slightly from the others but was nevertheless clearly marked." We also observed certain rings that appeared as translucent ridges on the surface of the centrum; there were other rings, however, that resembled narrow, translucent bands without any surface eruptions, and still others that were mere suggestions of lines or bands.

Change in the Shape of Vertebrae With Growth of Fish

In the course of examining a wide series of vertebrae, it was noted that while the two cones of an amphicoelous caudal vertebra were nearly the same size in small fish, the posterior cone was larger than the anterior in large fish, indicating that the vertebra changed its shape with growth of the fish. The lengths of the two cones (vertebral radii) were measured and the ratio of the two measurements was plotted against the size of the fish (fig. 4). While the ratio was nearly 1 : 1 in the smallest vertebrae examined (fish around 50 to 60

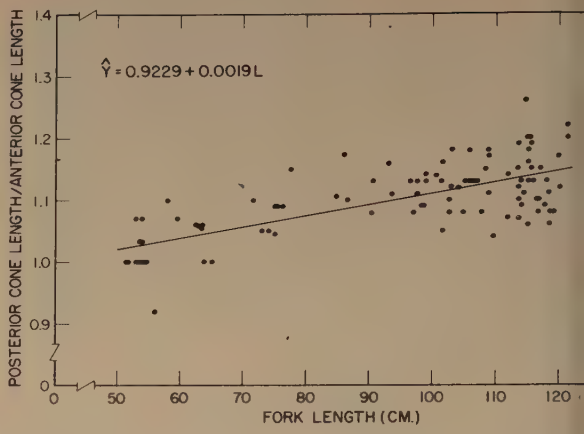


FIGURE 4.—Ratio of the average length of the poste and anterior cones plotted against fish size to dem strate the disproportionate growth of the two cone the amphicoelous vertebrae of albacore.

cm. long), the posterior cone was definitely lar than the anterior in the larger vertebrae. T changing proportion is described by the rectilin regression:

$$\hat{Y}=0.9229+0.0019\ L$$

where $\hat{Y}$ is the ratio of the two cones and L is fork length in centimeters. Although the cones of a caudal vertebra grow disproportionat each cone in itself exhibits a linear growth w growth of the fish. Thus, in working with cau vertebrae from a wide size range of fish, it important that any measurements of ring or ve bral radii, for the purpose of estimating the grov increments of the fish, should be confined to eit the anterior or the posterior cones and not averages of the two. By working with one co growth calculations can be based on the sim linear relation between size of the vertebrae size of fish.

Criterion for an annulus

Because of the great variability in the appe ance of the rings, it was extremely difficult formulate a satisfactory criterion for an annul In the beginning, we followed the definition Partlo (1955), who considered as annuli th rings which appeared as ridges on the centr surface. However, as will be discussed, original criterion was later expanded to incl rings which appeared as translucent bands w no surface eruptions.

ults of ring counts

After deciding upon the criterion to be followed, made a series of independent ring counts and g-radii measurements. A total of 9 series of nts and measurements resulted in agreements ween any 2 series of as low as 8 percent and high as 45 percent. There was poor agreement only between counts of the two readers but between counts made by the same person. ble 1 shows the best agreement attained be-

BLE 1.—*Best agreement in ring counts between two readers and between any two series of the same reader*

readers are designated as *A* and *B;* the numerals denote separate readgs; for example, A_2 represents the second reading made by reader *A*.]

dings compared	Percentage agreement	Percentage disagreement by:			
		1 ring	2 rings	.3 rings	4 rings
s. B_3	44.8	38.8	11.9	3.7	0.7
s. A_2	38.9	50.5	9.8	0.8	0.0
s. B_4	43.9	47.0	8.3	0.8	0.0

een readers (44.8 percent) and between sets of dings made by the same reader (38.9 percent reader *A* and 43.9 percent for reader *B*). ile most of the disagreement was by 1 ring to 50 percent), discrepancies of as many as ings occurred in many of the comparisons. nsistency was often not achieved even between nts of the anterior and posterior cones of the ne vertebra.

t was observed that much of the inconsistency he counts could be attributed to the difficulty istinguishing rings near the vertex of the cone also at its margin. This does not mean, how-, that the rings on the central portion of the es were clear and easily distinguishable, be-se here also there were many inconsistencies.

nples from small fish

ge determination by means of hard parts frently becomes more difficult and often breaks n completely in older fish. Therefore, atpts were made to age fish less than 90 centeters in length in order to determine whether ot the use of vertebrae from larger, older fish the cause of the poor results. In one trial isting of two series of counts, the agreement 56 percent for fish less than 90 centimeters ompared with 30 percent for larger fish. The er agreement with smaller fish is, of course, e expected because of the fewer rings. Further trials with samples of small fish disclosed that the counts were still far too variable to be acceptable as indicators of age.

The vertebrae were examined under natural and incandescent light and also under polarized and various colored lights with no noticeable improvement in the appearance of the rings. Various types of stains were also tried, but here again the results were disappointing from the standpoint of improving the readability of the rings. Thus, we found that we could not satisfactorily duplicate ring counts and therefore could not meet the first prerequisite to the use of vertebrae for aging albacore. Our findings are in contrast to Partlo's, who reported that "counts of rings were reproducible with high consistency."

Determination of time of ring formation

In order to validate the vertebral method for aging albacore, it is necessary that some direct evidence be obtained to show that the rings on the centra are true year marks, which are laid down annually. It appears reasonable to assume that if these rings are laid down regularly once each year, rather than randomly, a study of the margins of vertebrae collected periodically throughout a year should indicate the approximate period of ring formation. The width of the margin from the last ring to the edge of the centrum (the increment of the last ring) should be at a maximum immediately before, and at a minimum just at or after the formation of the last ring. A description of such a method of analysis for the determination of time of ring formation on tuna scales is given by Nose and others (1955).

An attempt was made to obtain some indication of the time of ring formation, despite the fact that any such study would probably be futile unless the rings or annuli could first be read with assurance. Measurements were made from the mid-point of the centrum to the margin of the vertebra (vertebral radius *T*) and to the last ring (ring radius R_n). Although the last ring was carefully selected in each instance, there was a possibility of error because rings on the margins were often indistinct. The difference between the vertebral and last-ring radii was considered the increment. Figure 5 shows a plot of the relative increment (absolute increment/vertebral radius) plotted against the month of capture of the fish. The data show no indication of regularity in time

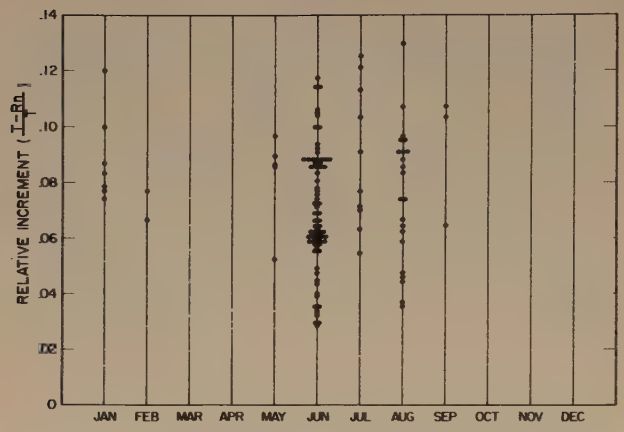


FIGURE 5.—Relative increment of the last ring plotted by month of capture of the fish.

of ring formation. Similarly, a plot of the absolute increment against time of capture resulted in a random scatter of points.

DISCUSSION

Previous investigators working on albacore age and growth have reported the presence of definite rings on the inner surface of the centrum of albacore vertebrae which, they believed, could be used as age indicators. They concluded that each of these rings represented an annulus and, therefore, assigned fish to specific age groups after making counts of these rings. Aikawa and Kato (1938) found that Uno's mean lengths (Uno 1936a, b) for age groups IV, V, and VI fell within the length range that they had established for these same age groups. Partlo (1955), on the other hand, found his ring radii values to be at variance with those observed by Aikawa and Kato, but stated that the disagreement was largely caused by the latter's not recognizing the ring closest to the vertex of the cone. Aside from this discrepancy, there was remarkable agreement between their ring radii values. Figueras (1955), who based his work largely on Partlo's technique, concluded that his results were in fair agreement with the latter.

Aikawa and Kato, Figueras, and Uno, so far as can be determined, have not satisfactorily established or presented any evidence showing that the rings on the vertebrae are age rings and annual in nature. Partlo, however, hypothesized that the rings are true year marks by the following: (1) by assuming that the length groups in the size frequencies are age groups, he found that there was acceptable agreement between the me length of fish assigned to each vertebral ring-cl and the mean length of corresponding leng groups in the sample, and (2) there was agr ment between the lengths of young fish calcula from vertebral measurements of older fish and observed lengths of young fish. For the latt Partlo, working with a subsample of 98 fish, fou that the observed lengths were consistently grea than the calculated lengths because the fish w captured some time after the last ring was form Partlo concluded that "from the above it see clear that the third and subsequent vertebral ri are produced annually. It is assumed, in absence of contrary evidence, that the inner t rings are annual also."

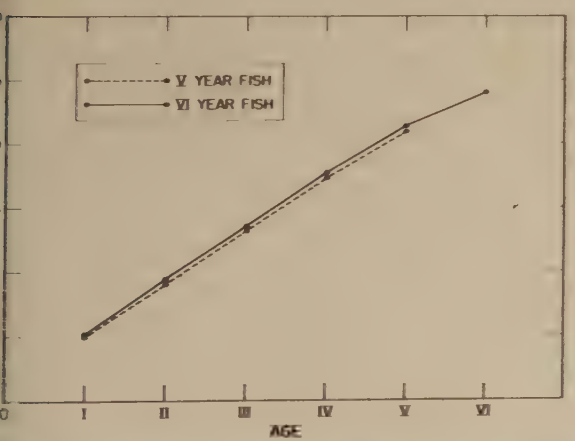
While Partlo's results indicated that the ver bral rings were true year marks, it was felt th more direct evidence would be desirable. C possible approach to obtaining such evidence presented on page 357.

In this study, ring counts were not reproduci with consistency, due largely to the difficulty formulating suitable criteria for the identificati of the rings. Since it was demonstrated that th was a linear relation between the vertebral radi and the body length of the albacore (fig. 4), it w difficult to make a reading without first formi an opinion as to how many rings a certain-siz vertebra should have. Also, in making ring me urements the selection of a ring often depended whether or not its radius fell within a cert range which encompassed all previous radii that ring. Any extreme deviation was inadve ently questioned, and a subsequent remeasureme was made on a more "reasonable" ring, which w invariably found after closer scrutiny. For ample, if the investigator measures the radius the second ring at 5 mm. in a particular verteb and if all previous second-ring radii have fall between 3 and 4 mm., he re-examines the verte for a second ring which he may have "misse More often than not he will "find" the "missin ring. In fact, it was observed that "rings" cou be located at will almost anywhere on the centru

Aikawa and Kato (1938) state that "where t variation of the radius in comparison with oth rings is very marked, the line cannot be consider an annual ring." Figueras (1955) found that 40 percent of the specimens he examined, the fi annulus as well as the succeeding annuli were

d closer to the center of the centrum than the esponding annuli in the remaining specimens percent). He therefore considered the 40 ent to belong to a different spawning season discarded them from calculations of growth ements. From the above, it appears that e workers also experienced some difficulty in lly adhering to established criteria.

he fact that we have not been able to repro- e ring counts with any reasonable consistency not in itself prove that this method of aging core is invalid. There are other points which ld also be considered. As stated earlier, no ct evidence has yet been presented to show the rings on the vertebral centra are "annuli." thermore, if we examine the results presented ome of the other workers, we find that the in- ents that are noted do not give either a rea- ble or consistent pattern of growth. Referring ikawa and Kato's results, Brock (1943) stated "it may be seen that the growth increment the age of one to that of eight is exactly the e each year, resulting in a growth curve that bsolutely linear. This is totally at variance what is known of growth curves in general in all other species of fishes that have been ied. If the number of "age rings" bears this tionship to the length of the fish it is probable they do not represent annuli and bear no ct relationship to age." Partlo's results are ewhat similar. In figure 6 we show a plot of y-length at earlier ages as calculated from 5- 6-year fish; the data were derived from Partlo 5: table VIII, p. 57). The calculated lengths



RE 6.—Calculated lengths of albacore at earlier ages sed on 5- and 6-year fish. (Taken from Partlo, 1955, ble VIII.)

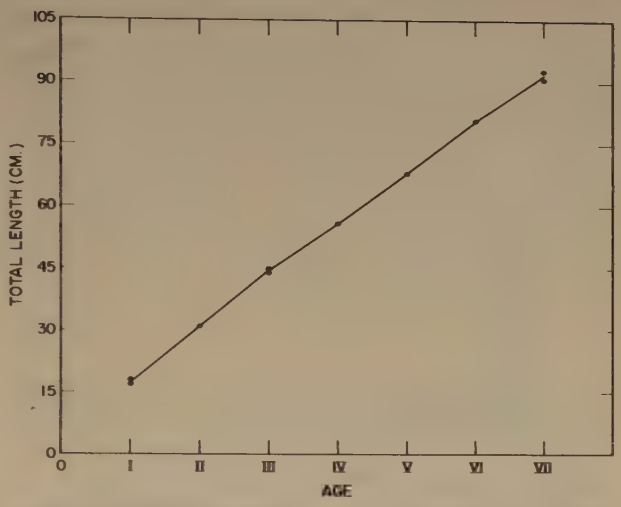


FIGURE 7.—Mean length at each age of albacore captured off northwestern Spain as reported by Figueras (1955). (Lengths given are total lengths.)

from ages 1 to 4 based on 5-year fish and the lengths for ages 1 to 5 based on 6-year fish form curves which are almost perfectly linear. The results presented by Figueras are shown in figure 7. Here again, the growth curve is remarkably linear, contrary to the general concept of growth curves.

Another consideration is that the various estimates do not appear to be consistent with growth as evidenced by tag returns. The information from this source is meager, however, and not much weight should be given it at the present time. A summary of albacore tag recoveries is given in table 2. The 5 tag recoveries which contribute information on growth are shown in figure 8.

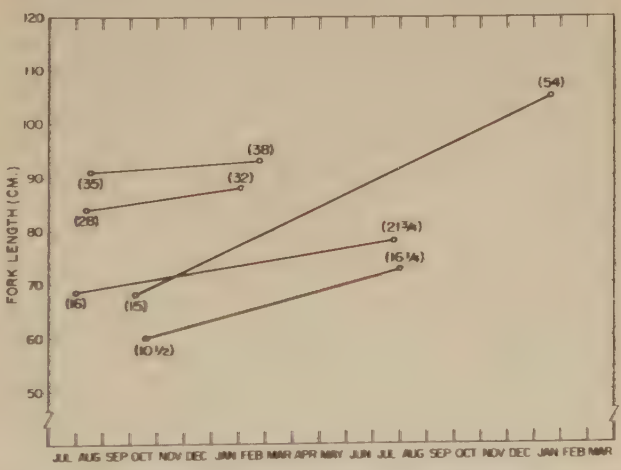


FIGURE 8.—Growth shown by 5 tagged albacore; data presented in table 2. (Body weight, in pounds, in parentheses.)

TABLE 2.—*Albacore tag recoveries reported by POFI and the California Department of Fish and Game* [1]

No.	Date of release	Locality of release	Released by	Date of recovery	Locality of recovery	Fish size	
						Release	Recov
						cm.	*cm*
1	Aug. 4, 1952	33°25′ N., 118°15′ W	CF&G [2]	June 23, 1953	31°30′ N., 149°40′ E	76	
2	Aug. 11, 1953	Guadalupe Is	do	Feb. 2, 1954	36°40′ N., 178°12′ E	84	
3	Aug. 16, 1953	do	do	Feb. 23, 1954	30°10′ N., 178°54′ W	91	
4	Sept. 26, 1954	33°42′ N., 121°15′ W	do	Apr. 6, 1955	31°55′ N., 143°15′ E		
5	Oct. 4, 1954	46°30′ N., 159°18′ W	POFI [3]	Nov. 28, 1955	35°45′ N., 157°39′ E	78.2	
6	Oct. 5, 1954	43°31′ N., 161°16′ W	do	Jan. 19, 1956	35°23′ N., 141°20′ E	68	
7	Oct. 9, 1955	42°16′ N., 147°16′ W	do	June 24, 1956	31°54′ N., 158°37′ E	63.4	
8	Oct. 17, 1955	44°55′ N., 144°48′ W	do	Aug. 1, 1956	31°21′ N., 117°17′ W	59.9	(16¼
9	July 31, 1956	44°31′ N., 174°55′ W	do	July 23, 1957	30°08′ N., 119°03′ W	68.4	(21¾ I

[1] The data for the California tag recoveries are derived from the reports of Ganssle and Clemens (1953), Blunt (1954), and Anonymous (1955).
[2] Department of Fish and Game, Sacramento, California.
[3] Pacific Oceanic Fisheries Investigations, U. S. Fish and Wildlife Service.

Variable growth is indicated, ranging from 2 cm. in about 6 months to 37 cm. in 16 months (4 to 28 cm. per year). The weights indicated in figure 8, with the exception of the last two recoveries (Nos. 8 and 9, table 2), are estimated weights based on the following length-weight relation:

$$\text{Log Weight} = -7.0239 + 2.87912 \text{ Log Length}$$ [1]

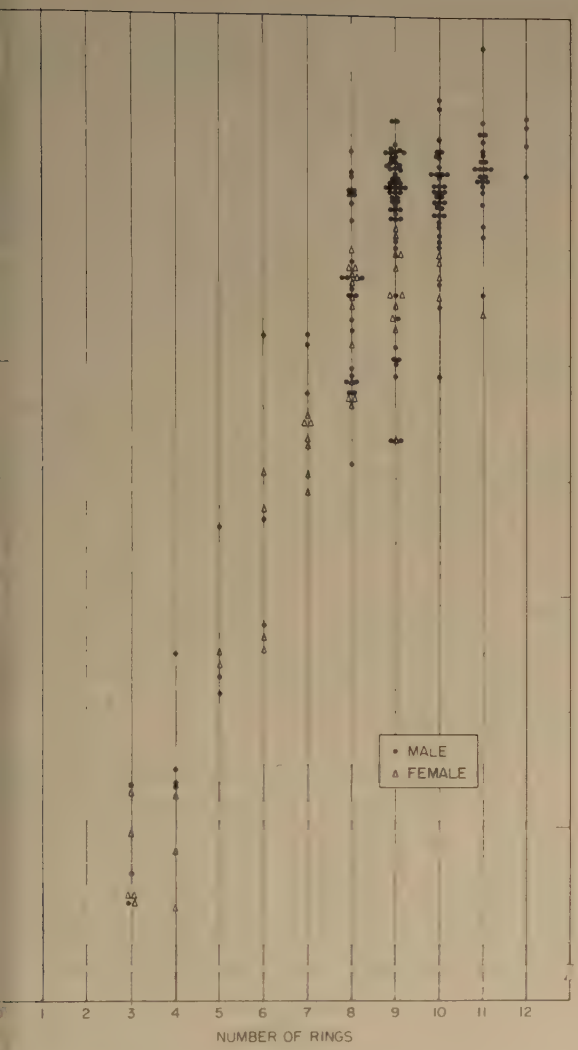
In terms of weight, a rough estimate of growth amounted to 6, 9, 27, 6, and 10 pounds per year, respectively, for the 5 fish shown from top to bottom in figure 8. Clearly, no conclusions can be drawn from these data. It is to be noted, however, that there are indications here of a moderately rapid growth rate, somewhat greater than the various estimates provided by the vertebral method of age determination.

It is possible, of course, that the rings on the centra are associated with growth but not necessarily with age of the fish. Unlike many of the fishes of the north temperate zone, it appears that albacore live under fairly uniform conditions by migrating to areas where food is available and where water temperature is suitable. They are not subject to extremes of winter and summer conditions as are certain fishes that occupy a more limited range. In the absence of any environmental extremes that might produce marked changes in the metabolic activity of the fish, it is quite possible that "winter" rings do not appear on the albacore's scales and vertebrae.

We have concluded that the rings on the vertebrae are probably not age rings which are laid-down annually or at such regular intervals that they can be used to tell the age of the fish; however, even if the rings were laid down randon with respect to time, older fish in general wo be expected to possess more rings than the youn ones. Assuming this applies to the albacore, number of rings in relation to the size of might be used to differentiate rapidly grow fish from slower growing individuals. Counts rings in albacore separated by sex show that am larger fish, the females, at a given ring count smaller than the males (fig. 9). The number rings in the counts ranged from 3 to 12, and females were represented for each count up 11 rings. Although the female albacore parently do not grow so large as the ma having reached their maximum size at arou 112 cm. (fig. 10, also Otsu and Uchida, 1959), ring counts indicate that the largest females m be about as old as the largest males.

A great predominance of males has been no among the larger sizes of several species of tu (e. g. Shomura and Murphy 1955). This uneq sex ratio among the larger sizes has been attr uted to "either differential mortality or differen growth, or to combinations of the two factor Differential availability has also been suggest For albacore there is a similar situation, somewhat more pronounced, for the males att a markedly larger size than females (fig. 1 Returning to figure 9, fish having 7 or m rings show growth differentiation by sex, males being the larger for each ring class. T bit of evidence suggests that after about seventh ring, the males have a faster grow rate than females. It is interesting to note t this apparent differentiation in growth commen when the fish attain a length of about 90 c which is the size at which albacore are belie

[1] Computed by POFI based on 77 fish (51–119 cm.) taken in the central North Pacific.



RE 9.—Ring counts shown by fish size and sex for one series of anterior cone readings.

each sexual maturity (Otsu and Uchida, 1959; anagi 1955). Thus, as juveniles, both sexes n to grow at about the same rate, then upon ining sexual maturity, the males outgrow the ales, so that among the larger sizes males ominate even though the larger females are as old as the larger males. If our assumption the rings on the vertebrae indicate "relative " is valid, then our data suggest that this omenon of unbalanced sex distribution among albacore is due primarily to differential th, with differential mortality or differential lability playing a possible secondary role. is also apparent that differential growth is the sole factor in operation here, since size

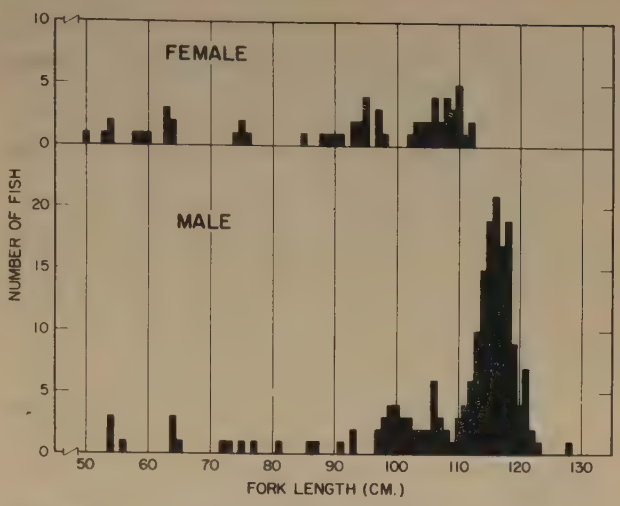


FIGURE 10.—Length and sex distribution of albacore used in this study. (The numbers of fish in smaller size classes differ from those of figure 1, which includes unsexed specimens.)

frequencies, such as in figure 10, lack a mode of large females of a magnitude comparable to the last mode of males. We would expect to find two large modes, one of females slightly to the left of that for males, in accordance with the difference in growth rates. This is not the case. Although evidence points to differential growth as being the main factor, other factors are probably acting in conjunction to cause the apparent reduction in numbers of the larger females. Here again, we must use caution in accepting any conclusions drawn from data presented in figure 9 since, ring counts could not be duplicated with any degree of consistency. Despite the questionable validity of these data, the fact that they showed the relatively smaller females to have, in general, nearly as many vertebral rings as the larger males has prompted the authors to present this discussion as a possible explanation of the puzzling phenomenon of unbalanced sex distribution encountered among the larger sizes.

SUMMARY AND CONCLUSIONS

(1) This study is based on the examination of vertebrae and scales collected from 212 Hawaiian and 53 central North Pacific albacore. In addition to scales and vertebrae, a cursory examination was made of the operculum, dorsal and pectoral fin spines and the hypural plate for possible indications of age.

(2) The sample represents fish taken by long-line, trolling, and gill nets during the period January 1955 to July 1956.

(3) None of the various structures examined revealed any markings which could be interpreted as age marks.

(4) Scales from 100 fish were examined; of these, the scales of 43 fish were considered unreadable. Samples from the remaining 57 fish varied greatly in degree of readability. A plot of the ring counts against fish size showed considerable overlapping between successive groups.

(5) Scales taken from the same fish were often of variable size. It was noted that small scales contained fewer rings than large scales, indicating that the origin of the scales was not uniform.

(6) Because of the undetermined nature of scale formation, and the fact that only about one-half of the scales were considered readable, further work with scales was discontinued.

(7) A change was observed in the shape of the caudal vertebrae with growth of the fish. Among the smaller vertebrae, from fish of about 50 to 60 cm. in length, the ratio of the length of the anterior cone to that of the posterior cone was nearly 1:1. The posterior cone was larger than the anterior in the larger vertebrae. Although the two cones of a caudal vertebra grow disproportionately, each cone in itself exhibits a linear growth with growth of the fish.

(8) In comparing independent sets of readings made by readers *A* and *B*, the highest agreement between the two readers was 44.8 percent. The best agreement between any two readings of the same reader was 38.9 percent for reader *A* and 43.9 percent for reader *B*. The most difficult rings to distinguish were those near the vertex and the margin of the cone.

(9) Although the vertebrae of small albacore were somewhat more readable than those of large albacore, it was still not possible to achieve sufficient consistency in ring counts and measurements to validate this method of age determination.

(10) The results indicated that the rings on the vertebral centra are laid down randomly with respect to time, rather than periodically. It is realized, however, that the validity of this method of analysis is questionable, since it is based on recognition of the last ring and since the counts could not be duplicated with any consency. If our results are valid, it would appthat the rings are simply growth marks rathan age marks.

(11) Considerable personal bias was inadvently introduced into the readings and measments. It was almost impossible to make a reing without first forming an opinion as to number of rings that should be expected overtebra of a certain size.

(12) The growth increments reported by vious investigators did not appear to give eia reasonable or a consistent pattern of growth

(13) The growth estimates of past investigado not appear to be consistent with growth evidenced by tag returns. Although the dderived from tagged fish are meager, they indithat albacore have a moderately rapid grosomewhat greater than the various estimaprovided by the vertebral method of age demination.

(14) Unlike many north temperate spewhich occupy limited environments, the albacappears to spend its life under fairly unifconditions by migrating to areas of abundfood and favorable water temperature. Thethese fish are probably not subject to the extrsummer and winter conditions which would ca"winter" marks to appear on scales and vertebr

(15) Although rings on the vertebrae probably not age rings which are laid doannually or at such intervals that they couldused to tell the actual age of the fish, it was poinout that the rings could possibly be used to asthe relative age, that is, older fish would hmore rings than younger fish.

(16) Results of a series of ring counts wexamined for differences between sexes. Thwas evidence that the unbalanced sex distributamong larger albacore, with a great predominaof males, was largely due to differential growhich sets in with the onset of sexual maturafter which the males grow at a faster rate tthe females.

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U. S. GOVERNMENT PRINTING OFFICE: 1959 O - 489034

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CHANGES IN TUNA LANDINGS OF THE HAWAIIAN LONGLINE FISHERY 1948–1956

BY RICHARD S. SHOMURA

FISHERY BULLETIN 160
From Fishery Bulletin of the Fish and Wildlife Service
VOLUME 60

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

UNITED STATES DEPARTMENT OF THE INTERIOR, Fred A. Seaton, *Secretary*
FISH AND WILDLIFE SERVICE, Arnie J. Suomela, *Commissioner*

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PUBLISHED BY U.S. FISH AND WILDLIFE SERVICE • WASHINGTON • 1959
PRINTED BY U.S. GOVERNMENT PRINTING OFFICE, WASHINGTON, D.C.

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C.
Price 20 cents

Library of Congress catalog card for the series, Fishery Bulletin of the Fish and Wildlife Service

U. S. *Fish and Wildlife Service.*
Fishery bulletin. v. 1–
Washington, U. S. Govt. Print. Off., 1881–19

v. in illus., maps (part fold.) 23–28 cm.

Some vols. issued in the congressional series as Senate or House documents.
Bulletins composing v. 47– also numbered 1–
Title varies: v. 1–49, Bulletin.
Vols. 1–49 issued by Bureau of Fisheries (called Fish Commission, v. 1–23)

1. Fisheries—U. S. 2. Fish-culture—U. S. I. Title.

SH11.A25 639.206173 9—35239*

Library of Congress [59r55b1]

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ABSTRACT

This study was undertaken to determine the cause of a change in species dominance in the catch of the Hawaiian longline fishery from yellowfin (*Neothunnus macropterus*) to bigeye tuna (*Parathunnus sibi*) during the period 1948–49. The available commercial catch records showed that the reversal in species resulted from a shift by the larger vessels of the fleet from fishing grounds in the leeward waters of the northern islands to grounds located in the windward waters of the southern islands. Bigeye tuna are more available to the fishery in the windward waters than in the leeward, whereas the yellowfin tuna are taken in greater numbers in the leeward areas. The bigeye season extends from October through May, whereas the best yellowfin catches are made during the summer months, June through August.

A hypothesis is given to explain the distribution and migration of the bigeye tuna in the central Pacific. Essentially, it postulates spawning in the tropical waters south of the Hawaiian Islands, a migration of young fish northward, a seasonal north-south movement of the adult population, and finally a continued southward movement to the tropical spawning grounds by adults in imminent spawning condition.

CHANGES IN TUNA LANDINGS OF THE HAWAIIAN LONGLINE FISHERY, 1948–1956

By RICHARD S. SHOMURA, *Fishery Research Biologist*

BUREAU OF COMMERCIAL FISHERIES

The Pacific Oceanic Fishery Investigations[1] (POFI) of the U.S. Fish and Wildlife Service s studied the hydrography and productivity of e central Pacific Ocean and has carried out ex- ɔratory fishing cruises to encourage the maxi- ım development and utilization of the high-seas ıery resources of this area.

One segment of POFI's task has been to gain understanding of the nature and problems of existing commercial fisheries in the central cific. Although small quantities of tuna are ɛn in Hawaiian waters by trolling and hand- e, the two major fisheries in the islands are pole-and-line fishery for skipjack (June 1951, mashita 1958) and the longline (flagline) ıery (June 1950, Otsu 1954) for the larger ɔsurface tunas. In a good year (1951) the pjack fishery landed 12,900,000 pounds with a ue of $1,700,000 (Yamashita 1958). The long- e fishery in 1952, a good year for that fishery, ıded tunas and marlins totaling 4 million unds and valued at $1,200,000 (Otsu 1954). ough these fisheries are small in respect to total ıdings, their strategic occurrence in midocean kes them ideal laboratories for the study of tain problems concerning midocean tunas.

The present study of the Hawaiian longline ıery was stimulated by Otsu's (1954) finding ıt from 1946 to 1952 there was a decline in land- gs of yellowfin (*Neothunnus macropterus*) and increase in landings of bigeye (*Parathunnus i*), with the reversal in dominance between 48 and 1949. The change in the bigeye landings especially noteworthy since it involved an in- ase from 12,000 pounds in 1946 to 2,200,000 unds in 1952, without a corresponding increase in the overall fishing effort as indicated by the total number of trips (Otsu 1954). The purpose of the present study was to describe the seasonal and long-term trends in the landings of the two species, and if possible, to determine cause of the fluctuations.

The basic catch data utilized in this report were supplied by the Hawaiian Division of Fish and Game, through the courtesy of Director Vernon E. Brock. T. Shimizu of the Division's staff helped to assemble the data for analysis. The longline fishermen provided valuable information on the fishery and personnel of the auction firms, Kyodo Fishing Co., United Fishing Agency, and Hawaii Fishing Co., made auction records available.

DESCRIPTION OF THE FISHERY

The Hawaiian longline fishery is the only American commercial fishery utilizing the long- line method, as developed by the Japanese (Sha- piro 1950), to capture subsurface tunas. The history and recent status of the fishery in Hawaii have been described by Brock (1949), June (1950), and Otsu (1954).

The longline fishery is dependent on vessels lo- cated at various ports throughout the Hawaiian Islands chain; however, the two major fleets are based at Hilo, Hawaii, about 10 vessels, and at Honolulu, Oahu, 31 to 33 vessels (Otsu 1954). These vessels range from 28 to 62 feet in length and are constructed along lines similar to the sampans used in the pole-and-line fishery (June 1951). They have a high, narrow bow with the wheelhouse and sleeping quarters located forward, leaving a spacious afterdeck of low freeboard. The latter facilitates the landing of large fish which, in the case of the marlins, occasionally exceed 1,000 pounds in weight. The vessels are

[1] Redesignated Bureau of Commercial Fisheries Laboratory, ıary 1, 1959.

ote.—Approved for publication, July 1, 1958. Fishery Bul- 360.

generally powered by high-speed diesel engines, and since they lack mechanical refrigeration systems the catch is stored in crushed ice.

The longline is made up of a number of units of gear called baskets which are joined in a series and allowed to drift free of the vessel (June 1950). Each basket of gear is composed of a cotton mainline section from which are suspended 4 to 6 branch lines each bearing a single hook. The longline is supported at the surface by wooden, glass, or metal floats. The number of baskets fished per day varies with the individual vessel but rarely does it exceed 40 baskets. By comparison, Japanese fishermen operating on a considerably larger scale may use more than 300 baskets of gear per set (Ego and Otsu, 1952).

The average length of a trip for a Honolulu-based vessel is 8 or 9 days and a majority of the trips are made within sight of land. The gear is set in the morning and retrieved in the afternoon. During the intervening period the line is patrolled and, if the fishermen are able to recognize the presence of a hooked fish by a submerged buoy, the fish is landed and the hook reset.

Composition of the longline catch is varied and consists of a number of species of tunas and spearfishes. In addition to bigeye and yellowfin, the tuna catch includes small numbers of albacore (*Germo alalunga*), skipjack (*Katsuwonus pelamis*), and on rare occasions bluefin tuna (*Thunnus orientalis*). Among the spearfishes the most commonly taken species are the striped marlin (*Makaira audax*) and black marlin (*Makaira ampla*),[2] while lesser numbers of white marlin (*Istiompax marlina*),[3] broadbill swordfish (*Xiphias gladius*), and shortnose spearfish (*Tetrapturus angustirostris*) are taken. Other species caught on the longline include the dolphin (*Coryphaena hippurus*), wahoo (*Acanthocybium solandri*), and various species of shark. Because of the wide variety of species taken and different periods of seasonal abundance, the fishery is capable of year-round operation.

MATERIALS AND METHODS

The basic data used in this study were derived from fish catch reports submitted by members of the fishing industry to the Hawaiian Division of Fish and Game. The form of this report used i the longline fishery has undergone several modifi cations; a sample of the present form is shown i appendix figure 1, page 105. The areas fished wer reported in code numbers indicated on a fisherie chart (app. fig. 2). The reported data were com pared with records kept by the auctioning firm and some adjustments made, especially for th early years when individual boat owners filled i the fish catch reports, for they occasionally com bined the catches of several trips and reporte them as a single trip. Also, the yellowfin an bigeye catches often were not separated accordin to species, but were combined in one or the othe species category. In recent years the auctio firms have filled out the forms after obtaining th essential data from the fishermen.

In addition to the sources given, more detaile information was obtained from 1949 to 1952 b interviewing vessel captains. These data forme the basis of Otsu's (1954) study and have als been utilized in this report.

Preliminary examination of the data showe that for an accurate evaluation of the fishery som selection of data would be necessary. Descrip tion of the method used follows.

SELECTION OF FLEET AND VESSELS

Initially, the study was limited to the Honolul based fleet, because the landings from this flee comprised more than 80 percent of the tota Hawaiian longline landings and accessibility o the Honolulu auctioning records made it possibl to check doubtful data. Limiting the study to th Honolulu fleet does not imply that the fishing are was proportionately restricted, since the large vessels at least fished throughout the majo Hawaiian Islands group.

It was also decided to limit the sampling to ve sels operating 5 or more of the 9 years under co sideration. This eliminated recent additions t the fleet, which were known to fish for longer p riods and with more units of gear than the olde vessels. Evidence that the bulk of the fleet wa the same throughout the period 1948 to 1956 indicated by the operation during 1956 of 23 o the total of 31 vessels comprising the 1948 flee This stability is in part a reflection of the sho period under study and the fact that most of th vessels were comparatively new. Of the 39 vesse

[2] Called blue marlin by continental Americans.
[3] Called black marlin by continental Americans.

ng from 1948 to 1956, 21, or more than half
ne total were launched during 1946 or 1947.

PARATION OF FLEET BY SIZE OF VESSEL

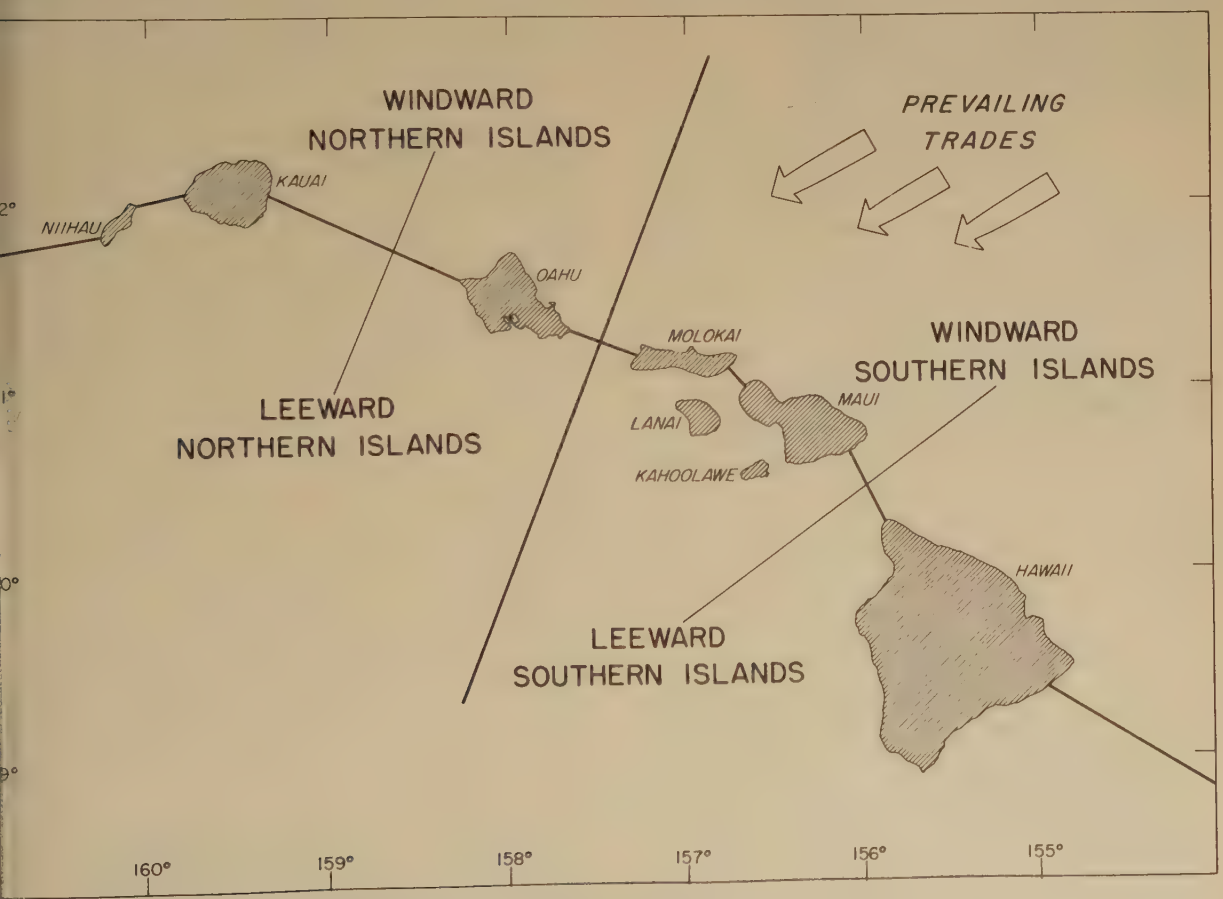
tsu (1954) stated that some of the Honolulu-
d longline vessels fished in waters around
u continuously throughout the year while
rs roamed the entire area, fishing as far as
northeastern shore of the island of Hawaii
. 1). The records showed that vessels fishing
usively around Oahu were smaller in size (reg-
ed length [4] of 45 feet or less) and fished fewer
s of gear and fewer days per trip. Accord-
y the vessels were classed, based on our knowl-
of the fishery, as small or large and the
h data for each class were treated separately.

THE TRIP AS A MEASURE OF EFFORT

ongline catch data have ordinarily been pre-
ed in terms of catch per 100 hooks (Murphy and Shomura, 1953). For the Hawaiian fishery, some data are available on the number of boat-days and the number of baskets fished in the early years, 1949 to 1952 (Otsu 1954), and for the years subsequent to 1955 the revised fish catch report includes the number of days at sea (app. fig. 1, p. 105). For the intervening years, 1953 to 1955, no such measures of effort are available. Even for the earlier period, 1949 to 1952, the data on the number of days fished are inadequate for a comprehensive study.

The only measure of fishing effort available for the entire period, 1948–56, is the number of trips. Thus, through necessity, the catch per unit of effort must be based on the catch per trip. To justify the trip as a measure of effort it was necessary first to determine whether there had been any changes in the length of trip during the period. Before 1952–53 some data were available on the number of days fished per trip, whereas for the subsequent years data were available on

[4] he vessel lengths were obtained from Annual Merchant ls of the United States, compiled by the U.S. Treasury rtment.



RE 1.—Chart of the major Hawaiian Islands subdivided into windward and leeward zones for areal studies of catch.

the number of days at sea. Excluding weather as a factor, these two measures are essentially the same for the small vessels. These vessels generally fish in the immediate vicinity of Oahu and are thus able to return to port the night of the last fishing operation. On the other hand, if the large vessels fish in the windward areas of the southern islands, they must travel from 120 to 2 miles from the fishing grounds to Honolulu. T introduces a possible differences of at least 1 d depending on the area fished, between the numb of days fished and the number of days at s Table 1 gives the average number of days of fi ing per trip for small and large vessels (the lat

TABLE 1.—*Number of days fished per trip, by size of vessel, 1949 to 1956*

[Vessels selected]

	1949–50	1950–51	1951–52	1952–53	1953–54	1954–55	1955–
Small vessels (<45 feet):							
Number of trips	41	52	47	107	88	201	
Average number of days fished per trip	8.3	8.2	8.4	8.0	7.9	7.7	
Large vessels (>45 feet):							
Number of trips	125	132	165	165	178	321	
Average number of days fished per trip	9.7	9.0	8.4	8.6	9.2	9.4	

adjusted for traveling time). There are no evident trends in length of trip for either vessel category. For the small vessels the average trip ranged from a low of 7.7 days during 1954–55 to a high of 8.4 days in both 1951–52 and 1955–56, with an overall average of 8.1 days for the entire period. For the large vessels, the number of days fished per trip (adjusted) ranged from a low of 8.4 days during 1951–52 to a high of 9.7 days for 1949–50. The overall average length of trip for the entire period for the large vessels was 9.1 days.

Another factor that should be considered in this evaluation of fishing effort is the number of baskets fished per day. As mentioned previously, the amount of gear fished per day was related to the size of the vessels, the larger vessels fishing more baskets of gear than the smaller. This difference is reduced in importance by the separation of the fleet into the two size categories. Some data are available on the number of baskets fished per day for the years 1950, 1952, and 1955 (table 2). There is some evidence that 1952 was an atypical year (Otsu 1954). If this year is omitt and only 1950 and 1955 considered, it appears t the number of baskets fished per day did change materially for either the small or the la vessels. In both years the small vessels fished average of 26 baskets of gear per day, whereas large vessels increased the amount of gear fis per day from 30 baskets in 1950 to 31 baskets 1955.

A final test of the trip as a measure of fishi effort is afforded by a comparison of the ca per trip with the catch per 100 hooks in th periods for which both kinds of data are ava able. Unfortunately, however, the only year w adequate data was 1952, which has been c sidered atypical. Nevertheless, a plot (fig. 2) these two units shows that the two variables

TABLE 2.—*Number of baskets of gear fished per day, by size of vessel*

[Vessels selected]

	1950	1952	1955
Small vessels (<45 feet):			
Number of vessels	8	12	7
Average number of baskets fished per day	26	24	26
Range (baskets)	22–30	21–31	20–30
Large vessels (>45 feet):			
Number of vessels	17	18	16
Average number of baskets fished per day	30	28	31
Range (baskets)	21–36	25–32	24–35

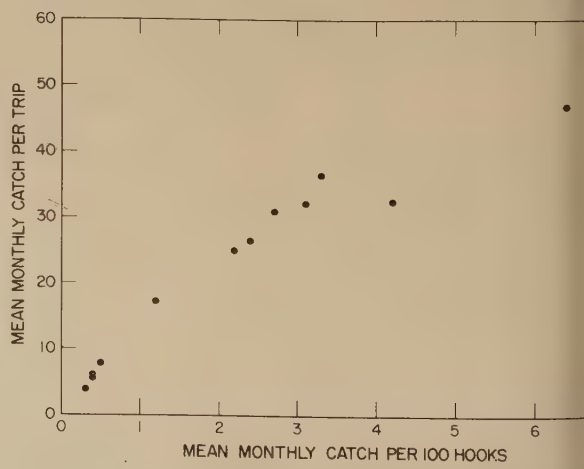


FIGURE 2.—Comparison of monthly mean bigeye catch 100 hooks and per trip in 1952.

osely correlated and exhibit a linear relation. e believe, therefore, that the catch per trip is e best attainable measure of availability of the o species of tuna to longline gear.

ANALYSIS OF THE DATA

The total Hawaiian landings of bigeye and llowfin, shown in figure 3,[5] include catches made various methods of tuna fishing, e. g., the long-ie, pole-and-line, trolling, and handline fishing. ie yellowfin catch has shown a steady decline om 1,325,000 pounds in 1946 to 446,000 pounds 1955, whereas the bigeye catch increased from a w of 199,000 pounds during the 1946–47 season a high of 2,710,000 pounds for the 1953–54 sea-n. Since 99 percent of the bigeye and about 85 rcent of the yellowfin are caught in the longline hery, the longline landings parallel the total ndings.

The trend in yellowfin landings of the Hono-lu-based vessels shows some divergence from e trends in the total catch by all methods and the total longline landings (fig. 3). Despite e steady decline observed in the overall catch, e yellowfin landings of the Honolulu fleet re-ained at a relatively stable level, averaging 5,000 pounds annually from 1948 through 1952. ien in the 3 years that followed, 1953 to 1955, e Honolulu landings dropped 30 percent to an erage annual figure of 275,000 pounds. Even is drop failed to keep pace with the decline of e overall catch, with the result that the Hono-u landings, which in 1948 and 1949 made up ly 36 and 38 percent of the total yellowfin catch the longline fishery, averaged 64 percent dur-g the next 6 years, 1950 through 1955. This lure of the trend in the Honolulu yellowfin ndings to parallel that for the Territory as a ole cannot be fully explained at present; it pears to be associated with operational aspects the fishery to be discussed later in this report. should be mentioned, however, that while the ta for the Honolulu fleet have been checked and rrected by means of various sources, the same s not been done for the remaining Hawaiian gline data.

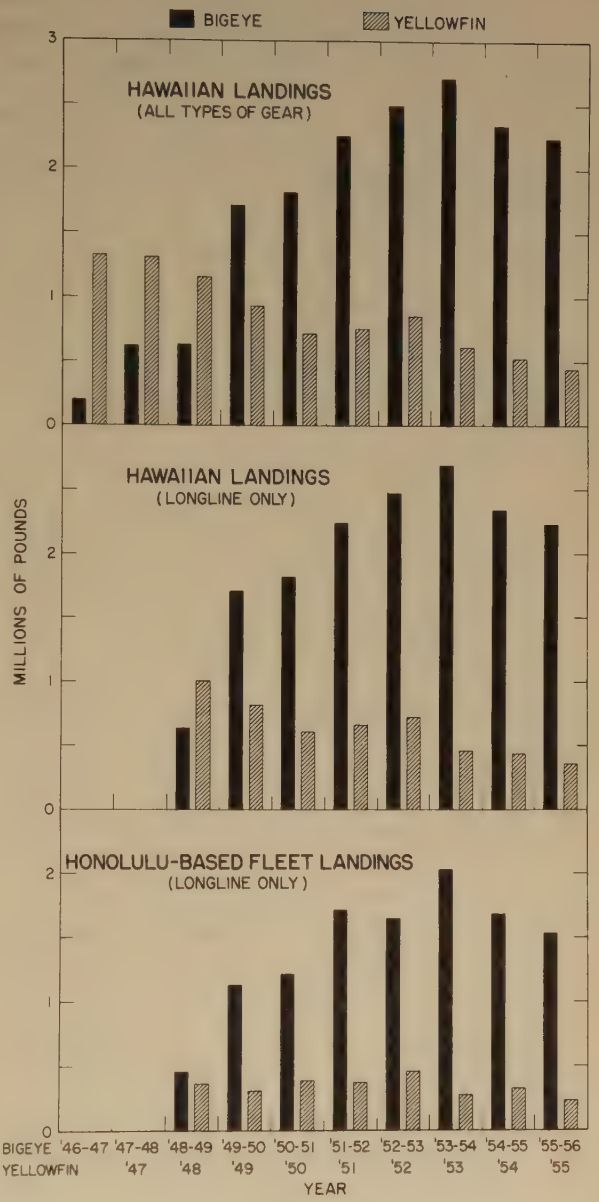


FIGURE 3.—Landings of bigeye (by fiscal year) and yellowfin (by calendar year), 1946 to 1956. (See appendix table 1.)

CATCH STATISTICS

Unless otherwise stated, the following discussions on landings and catch rates are in terms of numbers of fish rather than weight.

The bigeye catch of the selected large vessels varied directly with the landings of the entire Honolulu fleet, with a 300-percent increase between 1948–49 and 1953–54 and a decline thereafter (fig. 4). In contrast, the catch of the small

[5] Since the bigeye season occurs in the winter and spring months, the annual period for bigeye extends from July of one year through June of the following year. For yellowfin the calendar year is retained, inasmuch as the yellowfin landings reach a peak during the summer months.

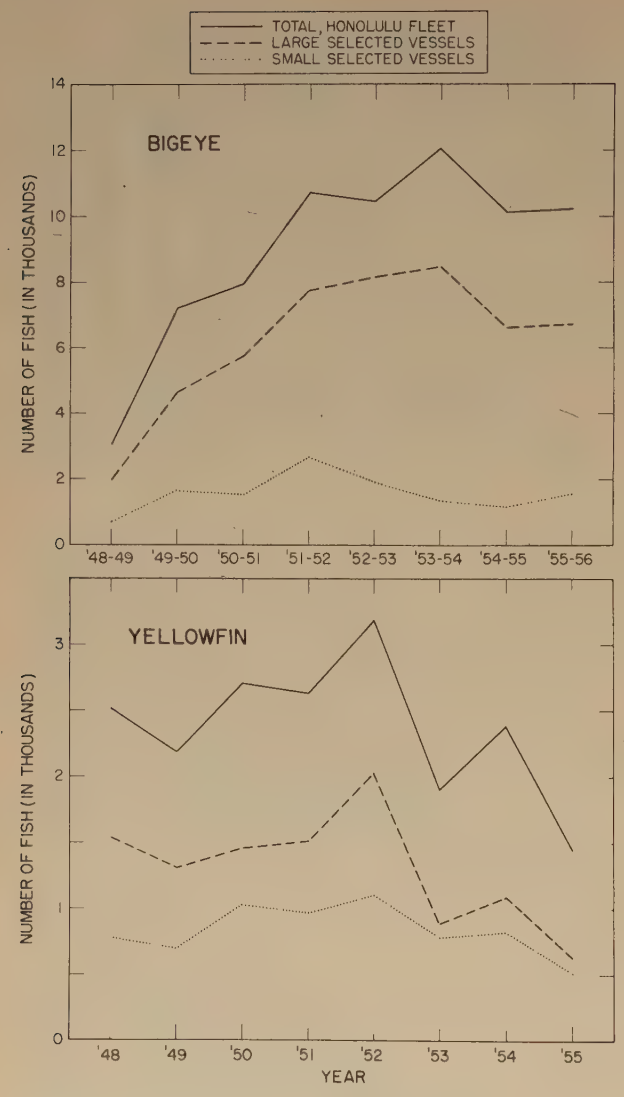


FIGURE 4.—Bigeye catch (by fiscal year) and yellowfin catch (by calendar year), by size of vessel.

selected vessels showed a slight rise from 1948–49 to 1951–52 and a decline thereafter. Thus, it appears that the tremendous increase in overall production was contributed by the large vessels.

The yellowfin landings, likewise, suggest that changes in the total catch were caused by changes in the landings of large vessels only. The most distinctive feature of the yellowfin landings (fig. 4) is the shift in relative proportion of the total catch obtained by the two classes of vessels. The proportion of the total yellowfin catch taken by the larger vessels was much higher before 1953 than it was during the last 3 years of the stu 1953 through 1955. Since this shift was coin dent with the increased bigeye catches of the lar vessels, it is evident that the changes in landin are related to factors affecting only the lar vessels.

FISHING EFFORT

Examination of the number of baskets fish per day and the number of days per trip indicat only slight variations in these measures of effo thus, any substantial changes in the overall effo if they did occur within the Honolulu fleet, shou be revealed in the number of trips made each ye Figure 5 shows that there was a steady increa in the total number of trips from 1948–49 1953–54 and a decline in the last two seaso 1954–55 and 1955–56. The increase was the res of more trips being made per boat, as shown the higher number of trips per boat-month (f 5), and also the result of more vessels being add than were lost to the fleet. The latter is indicat in table 3 by the increased number of trips of t nonselected vessels, which presumably were rece additions.

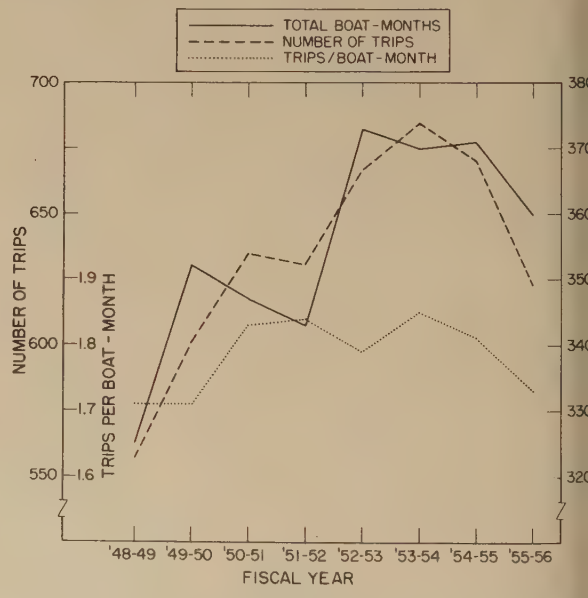
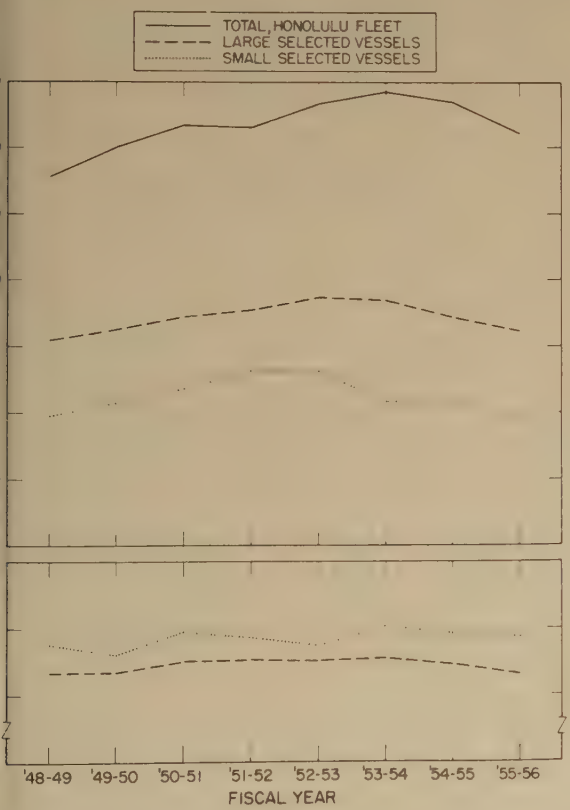


FIGURE 5.—Trends in fishing effort of Honolulu-ba fleet, 1948–49 to 1955–56.

In a comparison of the effort expended (fig. we find that both the small and large selected v sels followed the trend of the entire fleet.

TABLE 3.—*Effort expended by Honolulu-based fleet, 1948–49 to 1955–56*

Measure of effort	1948–49	1949–50	1950–51	1951–52	1952–53	1953–54	1954–55	1955–56
months:								
elected small vessels	105	119	119	136	141	108	111	100
elected large vessels	186	195	196	199	213	207	199	194
Total	291	314	315	335	354	315	310	294
onselected small vessels	4	4	5	1	12	12	12	12
onselected large vessels	30	34	27	7	7	43	49	54
Total	34	38	32	8	19	55	61	66
elected small vessels	197	215	236	263	264	218	219	193
elected large vessels	309	327	344	354	374	370	344	323
Total	506	542	580	617	638	588	563	516
onselected small vessels	4	6	8	2	19	24	27	19
onselected large vessels	47	53	46	12	10	73	81	88
Total	51	59	54	14	29	97	108	107
per boat-month:								
elected small vessels	1.88	1.81	1.98	1.93	1.87	2.02	1.97	1.93
elected large vessels	1.67	1.68	1.76	1.78	1.76	1.79	1.73	1.66



URE 6.—Trends in fishing effort of small and large vessels, 1948–49 to 1955–56.

CATCH PER UNIT OF EFFORT

The marked seasonal variation in catch per unit effort for the bigeye and yellowfin tuna is wn in figure 7. The peak catch of yellowfin urred during the summer and of bigeye during the winter and spring months. Of interest is the difference in catch rate for the two species in relation to size of vessel. The bigeye catch of the large vessels was considerably higher than that of the small vessels, the difference being more evident during the later years. On the other hand, with respect to yellowfin, the large and small vessel catch rates were nearly equal, the large vessels having only a slightly higher average catch.

The increase in bigeye catches and the difference in relative fishing success by vessel size for the two species can be better illustrated by the average annual catch rates (fig. 8). The large vessels experienced a sharp increase from 6.5 bigeye per trip during the 1948–49 season to 21.9 during the 1951–52 season, an increase of about 240 percent. The catch rates in subsequent years were stable at this high level, with only a slight decrease during the last two seasons, 1954–55 and 1955–56. The small vessels, on the other hand, exhibited minor fluctuations in the bigeye catch rate during the eight seasons, but the catch remained at a relatively low level.

The yellowfin catch rates (fig. 8) varied irregularly. The small vessels had a stable yellowfin catch rate of three to four fish per trip from 1948 through 1954 and a noticeable decline in 1955. On the other hand, the large vessels experienced two levels of fishing success. The first and higher level during 1948 through 1952, when the catches ranged from four to five yellowfin per trip, and the second and lower level persisting through the last three seasons, 1953 to 1956, with a catch rate

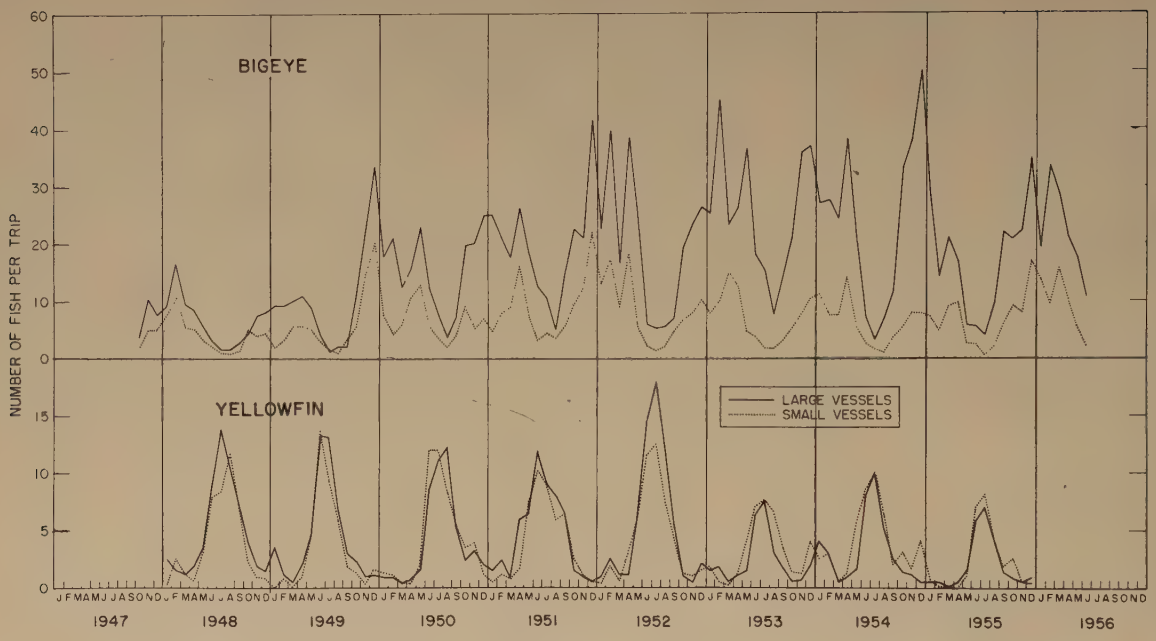
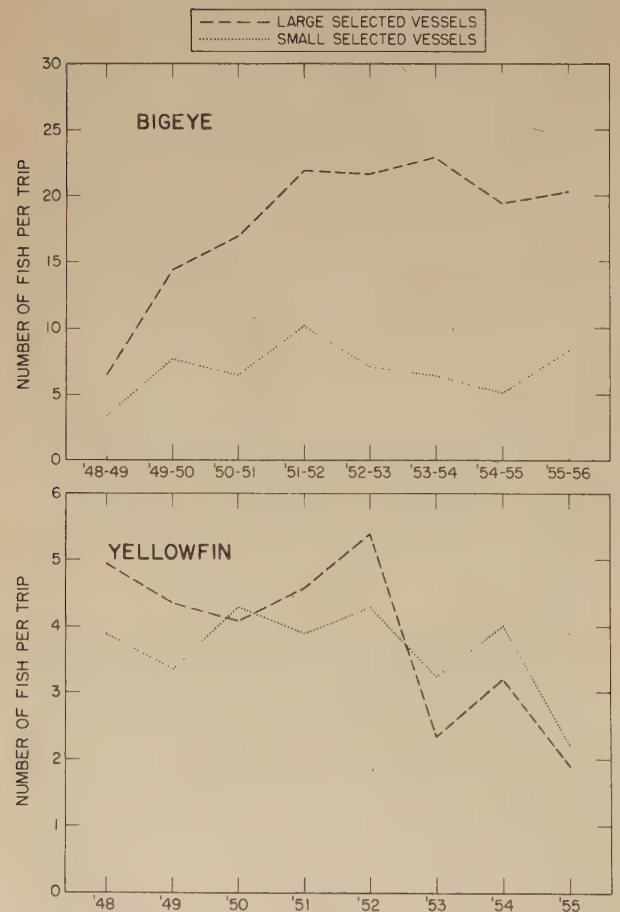


FIGURE 7.—Average catch per trip of bigeye and yellowfin tuna, by month and by vessel size.



of two to three yellowfin per trip. The most sig nificant feature of this change in level is that fo the last three seasons the catch rate of the larg vessels was lower than that of the small vessel This difference is surprising when it is realize that the large vessels fished more days per tri and more units of gear than did the small vessel

Since the factors contributing to the trip as measure of fishing effort have been analyzed an found to be stable, especially when vessel size h been adjusted, the discrepancies observed must b explained by changes in availability of the specie either by fluctuations in their actual abundance o indirectly by inherent differences in fishing succe in the various areas fished. With regard to abu dance, to explain the differences in bigeye cat by the two size groups of vessels would requi an increase in the bigeye population which did n distribute itself uniformly throughout the fishi areas. This is possible, but improbable, when on must explain a simultaneous decrease in yello fin abundance during the last three seasons—a d crease which would be confined only to the are fished by the large vessels. The most probab explanation which satisfies all these varying poin

FIGURE 8.—Average bigeye catch (by fiscal year) a yellowfin catch (by calendar year) per unit of effo by size of vessel.

difference in availability of the two species ong localities and an increased fishing effort by large vessels in areas containing more bigeye.

CHANGES IN FISHING AREAS AND EFFORT

Because of a limited range, the Honolulu-ed small vessels must confine their fishing to immediate vicinity of Oahu. The distribution heir trips, by season and area, is given in table Aside from a seasonal shift in effort, there ears to be no general change in fishing area hin the period studied. More than 80 percent he trips of these vessels were to the windward leeward areas of Oahu, and of these the lee-d areas received the greater effort. The small sels fished almost exclusively in the leeward as during the summer months, and although re is a noticeable increase in fishing effort in windward areas during the fall, winter, and ing months, the greatest percentage of the trips were made in the leeward waters at all seasons. The reason that the increase in effort was not more pronounced in the windward areas during the bigeye season may be that the small vessels prefer the calmer waters to leeward in spite of the greater availability of bigeye in the windward areas (Otsu 1954).

The distribution of trips by season and area for the large vessels is given in table 5. In general, these vessels tended to fish in the lee of the northern islands and on the windward side of the southern islands. During recent years there has been a pronounced shift in emphasis from the former to the latter area. With the exception of the winter of 1948–49, the majority of the fishing during the winter season has been in the windward areas of the southern islands. Also notable is the small yet consistent fishing effort in the windward areas of the northern islands, which could be in response to a greater availability of bigeye in these waters.

TABLE 4.—*Percentage distribution of trips of small vessels, by season and area, 1947 to 1956*

Season	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956
g:										
orthern Islands:										
Windward Kauai				13	5	5	10			
Leeward Kauai		6	23			10				
Windward Oahu		32	12		5				62	6
Leeward Oahu		36	65	87	89	85	62	95	33	94
outhern Islands:										
Windward Maui-Molokai		6					3			
Leeward Maui-Molokai		17					24	5	4	
Windward Hawaii										
Leeward Hawaii		2								
Number of trips		47	52	54	57	20	29	22	24	16
ner:										
orthern Islands:										
Windward Kauai				2	2	2				
Leeward Kauai		17	8			2				
Windward Oahu		4				4				
Leeward Oahu		76	92	98	95	88	100	100	100	
outhern Islands:										
Windward Maui-Molokai		2			3	4				
Leeward Maui-Molokai										
Windward Hawaii										
Leeward Hawaii										
Number of trips		46	48	60	60	51	27	27	25	
orthern Islands:										
Windward Kauai			2							
Leeward Kauai		12	9	2						
Windward Oahu		12	2			12	4	9	28	
Leeward Oahu		72	85	96	90	71	88	91	72	
outhern Islands:										
Windward Maui-Molokai		5	2	2	10	17				
Leeward Maui-Molokai							8			
Windward Hawaii										
Leeward Hawaii										
Number of trips		43	47	58	48	59	26	23	25	
r:										
or hern Islands:										
Windward Kauai		3	4	3						
Leeward Kauai	4	9	2							
Windward Oahu	24	14	8	3	12	14	8	29	58	
Leeward Oahu	44	71	86	76	69	73	76	58	42	
uthern Islands:										
Windward Maui-Molokai	20	3		15	19	11	12			
Leeward Maui-Molokai	8			2		2	4	12		
Windward Hawaii										
Leeward Hawaii										
Number of trips	25	35	51	59	26	44	25	24	19	

TABLE 5.—*Percentage distribution of trips of large vessels, by season and area, 1947 to 1956*

Season	1947	1948	1949	1950	1951	1952	1953	1954	1955	195
Spring:										
Windward northern islands		20	3	28	41	2	19		26	
Leeward northern islands		23	68	29	49	42	7		12	
Windward southern islands		43	26	37	6	43	52	97	53	
Leeward southern islands		14	3	6	4	12	21	3	9	
Number of trips		70	68	86	81	81	42	35	34	
Summer:										
Windward northern islands		10	18	12	43	25		3		
Leeward northern islands		61	75	56	36	58	10	28	17	
Windward southern islands		13	4	29	18	16	87	44	67	
Leeward southern islands		16	3	4	3	1	3	25	17	
Number of trips		69	71	84	67	89	39	32	36	
Fall:										
Windward northern islands		18	24	17	11	23				
Leeward northern islands		55	27	41	22	10				
Windward southern islands		18	48	41	67	65	95	97	98	
Leeward southern islands		9	1	1		1	5	3	2	
Number of trips		77	82	83	85	77	43	34	40	
Winter:										
Windward northern islands	21	24	24	14	24	19	2		14	
Leeward northern islands	15	44	17	11	10	6	7			
Windward southern islands	52	31	59	74	67	75	86	100	78	
Leeward southern islands	12	1		1			5		8	
Number of trips	66	68	75	76	72	53	42	32	37	

Of the four seasons, the spring distribution of fishing effort was the most erratic. Even during this season, however, the effort was concentrated in the leeward areas of the northern islands and in the windward areas of the southern islands. In the earlier years, effort during the summer was concentrated in the leeward waters of the northern islands, but during the last three summers, 1953 through 1955, it noticeably declined.

The annual effort and catch of bigeye and yellowfin by the large vessels in the windward areas of the southern islands are summarized in figure 9. The effort increased from a low of 22 percent of the total annual trips made into this area during 1948–49 to a high of 88 percent during the 1953–54 season. The following two seasons showed a slight decline. Again the significant feature both of the bigeye and of the yellowfin catch is the position of each relative to the effort expended. It is evident that bigeye fishing was more successful in this area than elsewhere, judged by the consistently higher catch percentage, than would be expected from the amount of effort expended. On the other hand, the reverse is true for yellowfin, with the catch consistently lower than the effort expended, indicating that the area is not as good a fishing ground for yellowfin as for bigeye. From this it can be deduced that yellowfin are relatively more abundant in the leeward waters of the northern islands than in the windward waters of the southern islands.

The seasonal breakdown of catch and fishing effort for the windward areas of the southern islands is presented in figure 10. The bigeye and yellowfin catch and effort by season still follo the yearly trends. For all four seasons, the bi eye catch is consistently higher than expected fr

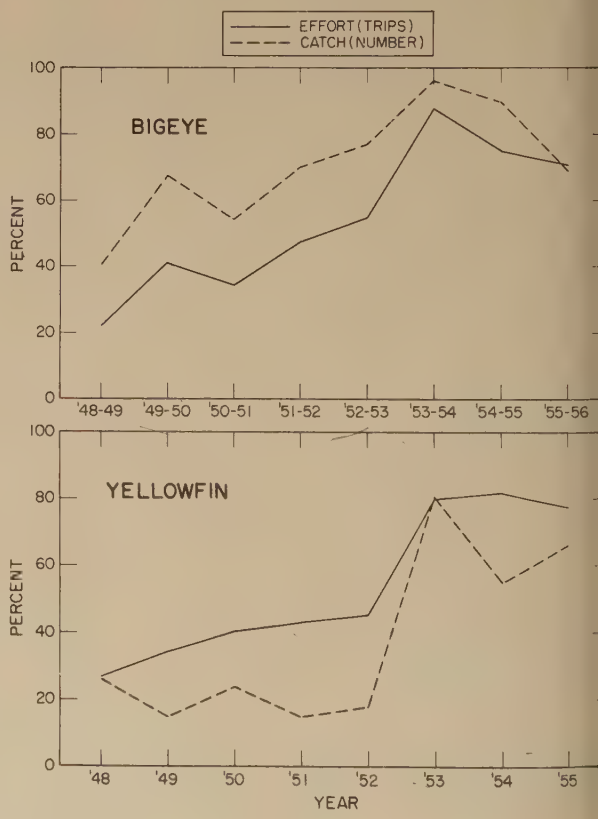
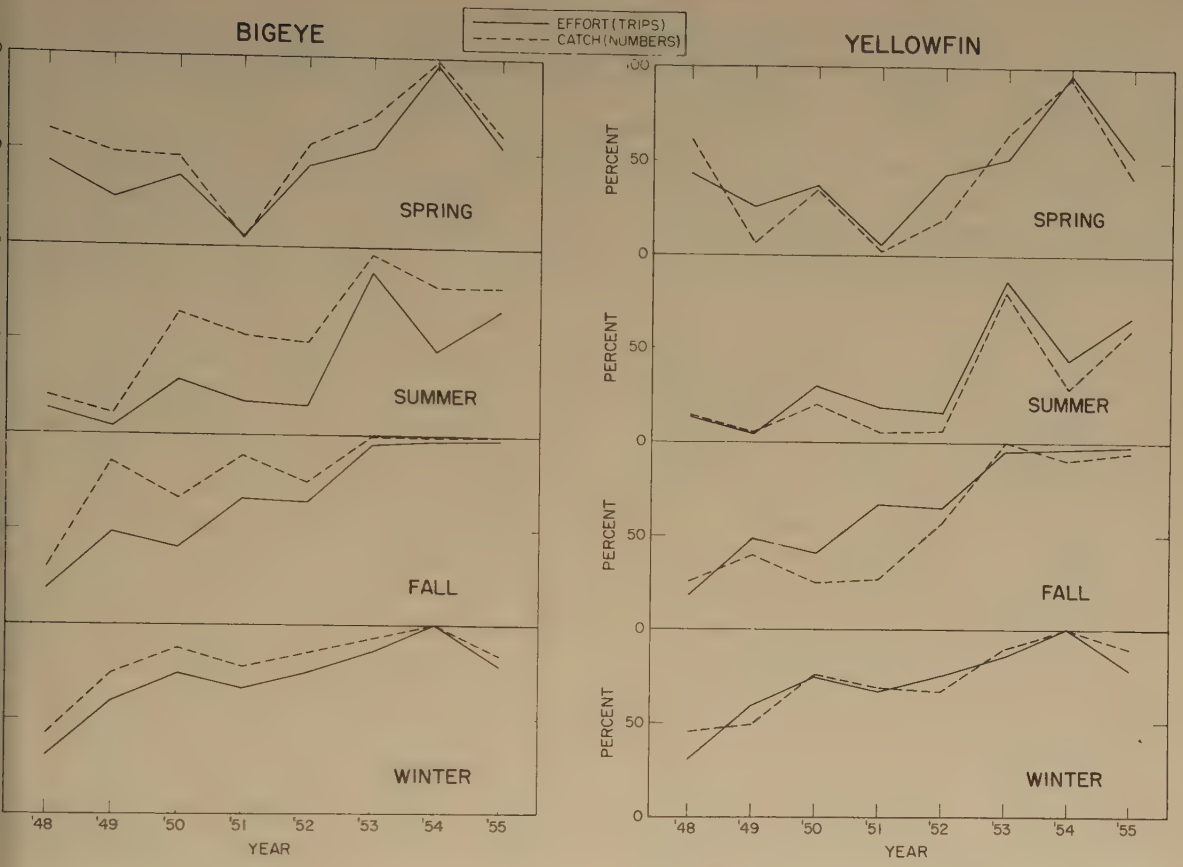


FIGURE 9.—Catch of bigeye (by fiscal year) and yellow (by calendar year) in respect to effort of large vess in windward waters of the southern islands. (appendix table 2.)



URE 10.—Bigeye and yellowfin catch and fishing effort of large vessels, by seasons, in the windward waters of the southern islands. (See appendix tables 3 and 4.)

amount of effort expended, whereas the reverse rue of the yellowfin catch. Thus it seems that differences in availability of the two species in se windward areas are real and not due to a 't in effort among the four seasons.

'irm evidence of areal differences in the availity of the two species is shown by a compari- of the distribution of effort and the resulting h in the windward area by the small vessels . 11). To reduce the variation due to the sea- al shift in effort, this comparison has been con- d to the winter and spring seasons, December ough May. Considering the small amount of available, the possibility of an error in the nitude of the catches cannot be denied; how-, the consistently higher percentage of bigeye n from the windward areas for the effort ex- led gives evidence that bigeye were more avail- in the windward than in the leeward areas. ortunately, a similar areal comparison cannot nade for yellowfin, since the small vessels fished almost exclusively in the leeward waters during the height of the yellowfin season.

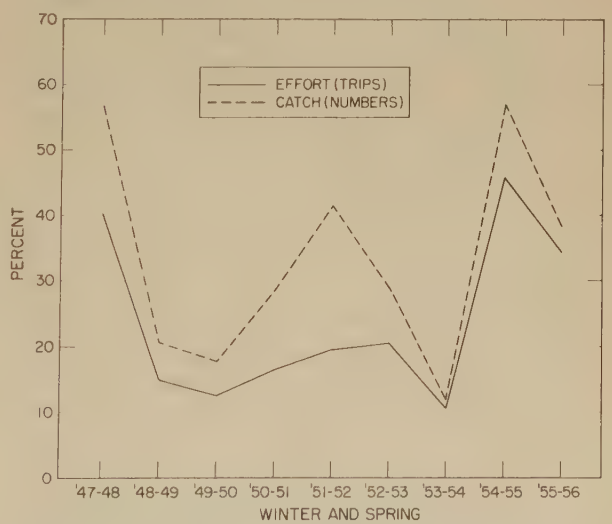


FIGURE 11.—Comparison of fishing effort and bigeye catch in windward areas by small vessels, winter and spring seasons combined. (See appendix table 5.)

In summary, the increase in landings of bigeye and the decline in landings of yellowfin can be related largely to a shift in fishing area by the large vessels from the lee of the northern islands to the windward waters of the southern islands. However, this does not preclude the existence of natural fluctuations in availability, since the catch rates of the small vessels, which did not participate in this shift, show a peak in bigeye during the 1951–52 season. Otsu (1954) points out that on several occasions during this season the catches were limited to prevent flooding of the fresh-fish market. The yellowfin, too, show natural fluctuations, as evidenced by the decline in catch rate of the small vessels during 1955.

SEASONAL DISTRIBUTION OF BIGEYE AND YELLOWFIN

A composite of the monthly average catch rates over the entire period is not the best means of depicting the seasonal distribution of bigeye and yellowfin tuna, but the lack of precise data precludes a detailed examination. This method, however, does show the seasonal trends and for this purpose the data are presented as such in figure 12.

The bigeye season can be considered to occur from October through May, when the large vessels made catches of better than 10 bigeye per trip and the small vessels from 5 to 12 bigeye per trip. The average monthly catches (fig. 7) for the large vessels showed considerable variation, which is reflected in the composite catch per trip, w peaks during December, February, and April a lows during January and March. On the ot hand, the small vessel category shows only depression covering January through Mar This double peaking of the bigeye catches for small vessels appears to hold true even for in vidual years; e.g., 1949–50 and 1953–54 (fig. One possibility which could account for the l points would be the inability of the vessels to f because of bad weather. This would be expect to affect the catch rates inasmuch as the trip used as the unit of effort. A cursory examinati of the days on which small craft warnings w issued by the U. S. Weather Bureau (table shows that there is some correlation of low catc with bad weather. At the present time, howev we are unable to make any quantitative estima of the effect of weather on catch and fishing effo

The yellowfin season extends over the summ months and unlike the more gradual entrance the bigeye into the fishery, the yellowfin ent abruptly during the month of June (fig. 1 This is indicated by the high catch rate of nea 10 yellowfin per trip for both small and la

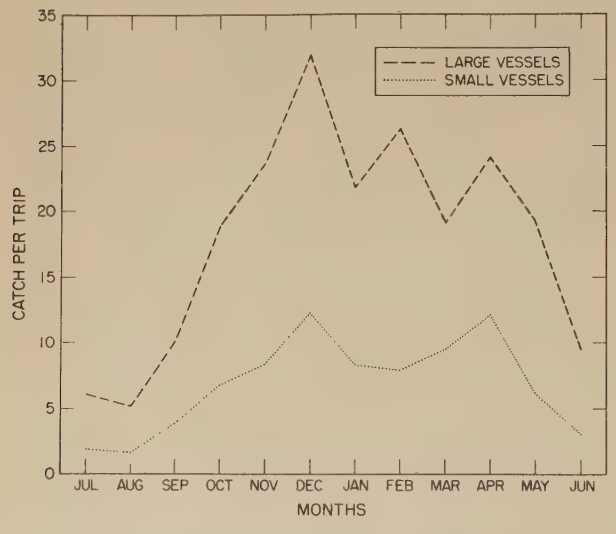


FIGURE 12.—Composite catch per trip of bigeye tuna for small and large vessels, July 1948 to June 1956.

TABLE 6.—*Number of days with small craft warning*

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	M
1951–52	2	4	1	3	0	9	1	
1952–53	0	10	1	0	4	0	0	
1953–54	1	6	1	3	2	3	1	
1954–55	1	3	8	1	9	5	6	
1955	0	9	2					

NOTE.—Unpublished data furnished by U.S. Weather Bureau.

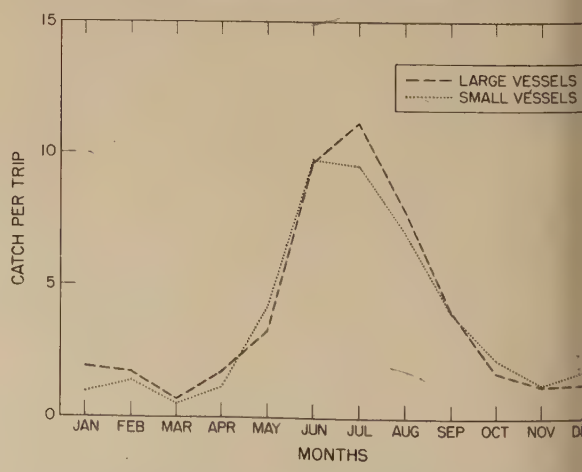


FIGURE 13.—Composite catch per trip of yellowfin t for small and large vessels, 1948 to 1956.

ssels during June compared with the low of out 4 fish per trip during the previous month. ie rapid decline of the catch rates during August d September, from eight yellowfin per trip to ur, also suggests a rather rapid movement of e yellowfin from the fishing grounds.

The yellowfin catch shows uniform single modes r both small and large vessels. This absence fluctuations could possibly be due to a more iform number of days fished per trip, a result the generally good weather which prevails dur- g the summer months. As pointed out in the rlier discussion, there are significant differences the relative fishing success for bigeye and yel- wfin, related to vessel size. The catch rates for llowfin by small and large vessels were approxi- ately equal throughout the year, whereas for geye the large vessels experienced 2.5 times bet- fishing than the small vessels.

SIZE OF FISH

The Hawaiian longline fishery, by virtue of the ethod of fishing, primarily exploits the large nas, a majority of the catch being composed of h exceeding 100 pounds in weight. The lack small fish in the catch is not due to their absence om the area, for Moore (1951) has reported that all bigeye and yellowfin are taken in Hawaiian ters by surface-fishing methods; but more ely it is due to a differential size segrega- n of the species with depth. Bigeye and yellow- appear to spend their early life near the rface and their adult life in deeper waters, thus small fish are not available to the deep-fishing ngline gear (Murphy and Shomura, 1953).

As noted previously and shown in figure 12, od bigeye catches are made in Hawaiian waters om October through May and only during the mmer months are the catches considered poor. their work on albacore and bigeye (Honma and mimura, 1955; Suda 1954), the Japanese have own that west of the 180° meridian these two ecies undergo a latitudinal migration, being en farthest to the north during the summer iod and to the south during the winter months. ey also present some evidence that at any given ne small fish are located to the north of the ger fish, the net result being a gradation in es with progressively larger fish to the south. ne evidence of such a phenomenon in the Ha- waiian fishery is indicated by the changes in average size of the bigeye (fig. 14). Despite the variability of the averages from month to month, the catch was composed of consistently smaller fish during the winter months, as is to be expected if the larger fish in a population sorted by size did move to the south during the winter.

Another interesting size variability in the catch is the consistently lower average size of bigeye taken by the small vessels as compared with those taken by the large vessels. This difference, which is most noticeable during the winter months (fig. 14), is clearly indicated in a comparison of the annual average size of bigeye by size of vessel (fig. 15). Although the magnitude of the differences is not important, the consistency of the relation, i.e., small fish being captured by small vessels, is striking. This may be confirming evidence of the size gradation with latitude, inasmuch as the small vessels operate in waters farther north than the large vessels.

The yellowfin also show considerable seasonal fluctuations in average size, with the larger fish occurring during the summer months when the catches are best (fig. 14). Unlike the bigeye, there are no pronounced differences in the annual average size of yellowfin taken by small and large vessels (fig. 15).

DISCUSSION

At present, little is known of the life histories of the various tuna species. Research has been conducted on various segments of the biology of the bigeye and yellowfin in Hawaiian waters (Brock 1949, June 1953, Otsu 1954, Iversen 1956, and Yuen 1955). Utilizing all available information, we have constructed a hypothesis to explain the presence of the bigeye in Hawaiian waters. In brief, this assumes that bigeye tuna spawn in tropical waters south of the Hawaiian Islands and that the young fish migrate to the north of Hawaii. Superimposed on this migration of the young fish are regular, seasonal north-south migrations of the adult population.

This explanation is based on the following information. Yuen (1955) established that the bigeye in Hawaiian waters are not in spawning condition, and thus their presence in the longline fishery cannot be attributed to a spawning run, such as was suggested for the yellowfin by June

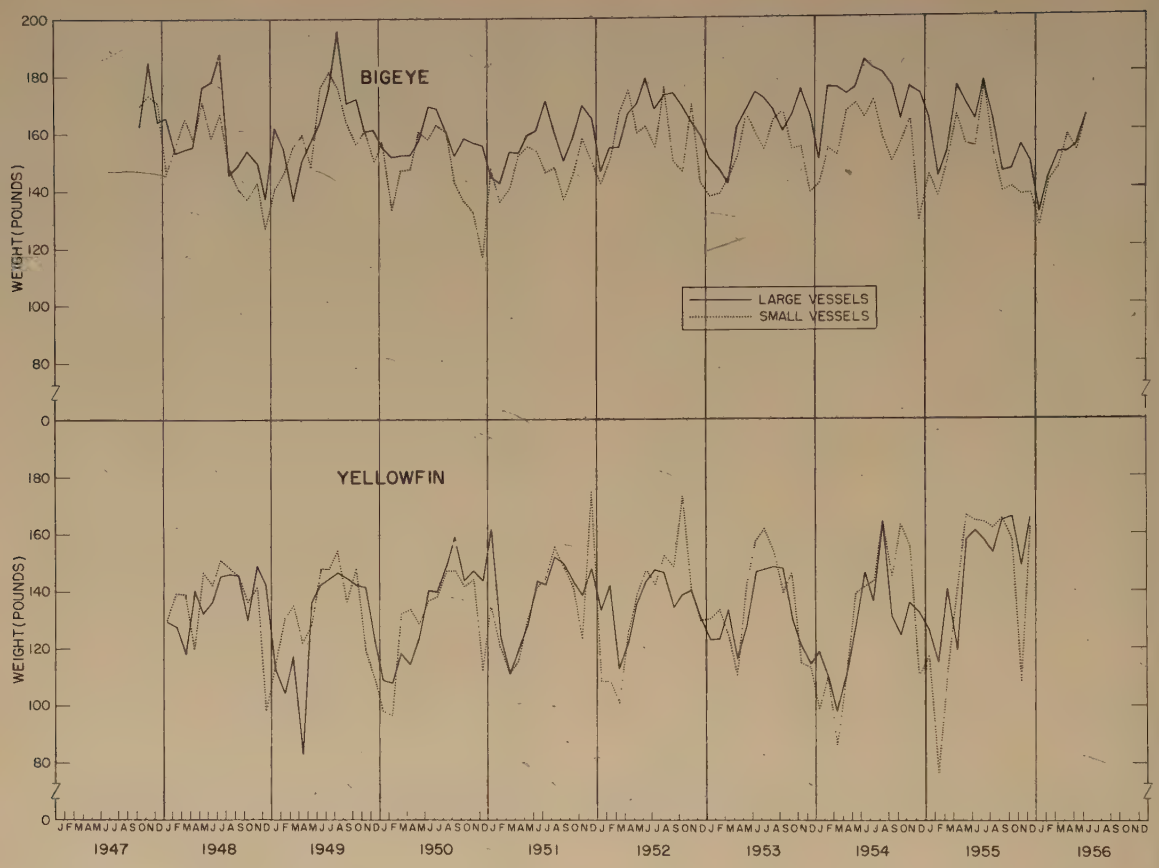


FIGURE 14.—Average size of bigeye and yellowfin, by months, in the catch of small and large vessels.

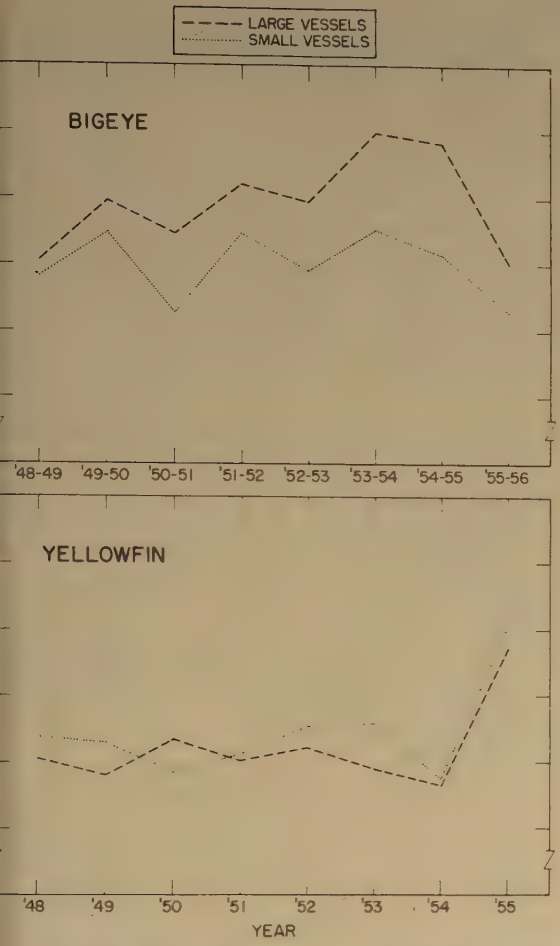
(1953). Maturation studies show that bigeye spawn more than once a year and that they have a widespread spawning area extending from the waters southeast of the Hawaiian Islands and westward to the Caroline Islands group (Yuen 1955). The presence of small bigeye in Hawaiian waters has been demonstrated (Moore 1951), but no studies have been made on the details of their distribution or seasonal variability.

According to our hypothesis, the adult bigeye population shifts southward during the winter, bringing the fish within reach of the Hawaiian fishery. Since the fish remain segregated by size, an auxiliary effect of this southern migration is to reduce the size of the fish taken in Hawaii in winter as compared with the size taken during the summer. Even during the winter it appears that the peak density of the population lies to the north of Hawaii, for Japanese vessels, specifically searching for bigeye, fish from 100 to 200 miles north of the Hawaiian Islands chain during January and February. Following the winter, th northward shift of the population leaves th Hawaiian Islands on the extreme southern fring of the distribution and the catch rates of bigey drop precipitously, though a few relatively larg individuals are taken. It is during this period o low bigeye catch that the large yellowfin move int the Hawaiian Islands area.

SUMMARY

1. A detailed examination of the catch record of the Honolulu longline fleet, covering the perio 1948 to 1956, was made to determine the cause of a marked increase in landings of bigeye tun and a decline in yellowfin.

2. A study of the fishing effort expended in th fishery showed a substantial increase in the tota number of trips, resulting from an increase in th number of trips per vessel and from the additio of new vessels to the fleet. The magnitude of th increase in effort was not sufficient, however, t



RE 15.—Average annual size of bigeye (by fiscal ar) and yellowfin (by calendar year) taken by small l large vessels.

unt for all of the increase in bigeye landings did not explain the decline in yellowfin.

When the catch-per-trip data were classified rding to size of vessel, they showed a gener- stable catch rate for both bigeye and yellowfin ne small vessels during the period under study an increase in catch per trip for the bigeye by arge vessels, accompanied by a decline in yel- n during the last 3 years (1953–55). This rgence was explained on the basis of a shift in of fishing by the large vessels. The small ls, which concentrated their efforts in waters unding Oahu, experienced uniform bigeye yellowfin catches. The large vessels, on the hand, shifted from the leeward areas of the ern islands to the windward areas of the ern islands. The increase in bigeye catch was due to the greater availability of bigeye in the windward areas as compared with the leeward areas. The decline in yellowfin catch rates by the large vessels during the last 3 years of this study was related to the increased fishing effort during the summer in the windward areas of the southern islands, which are areas of reduced yellowfin availability.

4. Annual variations in availability not due to areal shifts in the fishery were shown in the catch rates of the small vessels. The 1951–52 season was exceptionally good for bigeye, while the yellowfin showed a decline in availability during the 1955 season.

5. The bigeye captured by the small vessels were consistently smaller than those captured by the large vessels, and the smallest bigeye were taken during the winter months.

6. A hypothesis explaining the seasonal variability in bigeye distribution has been developed utilizing the results from various studies on the life history of the bigeye and on the commercial fishery. Essentially, it assumes that spawning takes place in tropical waters followed by a migration of the small fish northward to a center of abundance located north of the Hawaiian Islands. The adult population undertakes a north-south seasonal migration, spending the winter and spring months in Hawaiian waters, where it supports a sizable longline fishery.

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APPENDIX

APPENDIX TABLE 1.—*Annual landings (pounds) of bigeye and yellowfin tuna, 1946 to 1956*

Year	Total Hawaiian landings (all types of gear)	Total longline landings	Total landings Honolulu-based longline fleet	Year	Total Hawaiian landings (all types of gear)	Total longline landings	Total landings Honolulu-based longline fleet
:				Yellowfin:			
6–47	199,007			1946	1,324,767		
7–48	621,794			1947	1,314,349		
8–49	632,269	630,935	460,705	1948	1,158,111	1,006,460	365,717
9–50	1,707,884	1,706,035	1,138,454	1949	929,239	817,057	307,201
0–51	1,820,584	1,819,068	1,215,505	1950	720,537	605,315	383,916
1–52	2,252,985	2,248,640	1,721,017	1951	757,199	661,314	368,686
2–53	2,496,162	2,473,583	1,648,006	1952	855,655	719,326	454,819
3–54	2,710,437	2,699,890	2,032,208	1953	621,654	459,196	272,214
4–55	2,346,682	2,340,824	1,680,600	1954	525,770	435,551	322,237
5–56	2,241,782	2,231,468	1,528,922	1955	445,769	352,781	229,191

PENDIX TABLE 2.—*Catch of bigeye and yellowfin and fishing effort of large vessels in windward waters of the southern islands, 1948 to 1956*

I. BIGEYE (FISCAL YEAR)

	1948–49	1949–50	1950–51	1951–52	1952–53	1953–54	1954–55	1955–56
ard waters of southern islands:								
ort (trips)	62	131	110	149	133	138	101	106
tch (number)	740	3,053	2,919	4,922	3,540	4,170	3,179	2,786
as:								
ort (trips)	282	319	319	314	241	157	135	150
tch (number)	1,823	4,528	5,360	6,999	4,595	4,332	3,539	3,529

II. YELLOWFIN (CALENDAR YEAR)

	1948	1949	1950	1951	1952	1953	1954	1955
ard waters of southern islands:								
ort (trips)	76	99	138	129	150	129	110	112
tch (number)	367	191	335	188	325	283	260	161
s:								
ort (trips)	280	288	340	298	328	161	134	144
tch (number)	1,400	1,260	1,383	1,267	1,810	351	468	243

APPENDIX TABLE 3.—*Bigeye catch and fishing effort by seasons, of large vessels, 1948 to 1955*

	1948	1949	1950	1951	1952	1953	1954	1955
dward waters of southern islands:								
Effort (trips)	30	18	32	5	35	22	34	18
Catch (number)	328	337	695	76	1,190	806	1,166	379
areas:								
Effort (trips)	70	68	86	81	81	42	35	34
Catch (number)	545	693	1,437	1,670	2,198	1,164	1,181	643
r:								
dward waters of southern islands:								
Effort (trips)	9	3	24	12	14	34	14	24
Catch (number)	30	19	417	311	243	555	216	288
areas:								
Effort (trips)	69	71	84	67	89	39	32	36
Catch (number)	149	172	638	591	496	573	273	365
dward waters of southern islands:								
Effort (trips)	14	39	34	57	50	41	33	39
Catch (number)	101	735	838	1,541	1,001	1,251	1,249	1,048
areas:								
Effort (trips)	77	82	83	85	77	43	34	40
Catch (number)	347	856	1,247	1,726	1,322	1,264	1,258	1,052
dward waters of southern islands:								
Effort (trips)	21	44	56	48	40	36	32	29
Catch (number)	260	1,358	1,643	1,993	1,380	1,329	1,339	1,007
areas:								
Effort (trips)	68	75	76	72	53	42	32	37
Catch (number)	611	1,824	1,859	2,564	1,602	1,423	1,339	1,196

APPENDIX TABLE 4.—*Yellowfin catch and fishing effort, by seasons, of large vessels, 1948 to 1955*

	1948	1949	1950	1951	1952	1953	1954	1
Spring:								
Windward waters of southern islands:								
Effort (trips)	30	18	32	5	35	22	34	
Catch (number)	100	10	28	6	45	22	50	
All areas:								
Effort (trips)	70	68	86	81	81	42	35	
Catch (number)	162	153	82	339	221	34	53	
Summer:								
Windward waters of southern islands:								
Effort (trips)	9	3	24	12	14	34	14	
Catch (number)	111	40	177	33	81	158	75	
All areas:								
Effort (trips)	69	71	84	67	89	39	32	
Catch (number)	784	803	881	608	1,260	198	269	
Fall:								
Windward waters of southern islands:								
Effort (trips)	14	39	34	57	50	41	33	
Catch (number)	90	71	76	62	100	46	61	
All areas:								
Effort (trips)	77	82	83	85	77	43	34	
Catch (number)	341	181	307	233	176	46	67	
Winter:								
Windward waters of southern islands:								
Effort (trips)	21	44	56	48	40	36	32	
Catch (number)	61	33	117	57	78	100	24	
All areas:								
Effort (trips)	68	75	76	72	53	42	32	
Catch (number)	134	67	153	83	116	111	24	

APPENDIX TABLE 5.—*Bigeye catch and effort by small vessels in all windward areas, 1947 to 1956*

[Winter and spring seasons combined]

	1947–48	1948–49	1949–50	1950–51	1951–52	1952–53	1953–54	1954–55	195
Windward areas:									
Effort (trips)	29	13	13	19	9	15	5	22	
Catch (number)	231	83	191	279	272	221	63	255	
All areas:									
Effort (trips)	72	87	105	116	46	73	47	48	
Catch (number)	407	405	1,077	977	656	766	535	447	

BOARD OF COMMISSIONERS OF AGRICULTURE AND FORESTRY

FLAGLINE CATCH REPORT

DIVISION OF FISH AND GAME TERRITORY OF HAWAII C-5

Name of Permittee

Fisherman's License No.

Month ..... 19 .

Name of Boat

F.G. No

No. of Baskets Used

Day of Landing	No. of Days at Sea	Area of Catch	Port of Landing	AHI (Yellowfin) 003			BIG EYE (Bluefin) 006			AHIPALAHA (Albacore Tombo) 004			STRIPED MARLIN 009			BLACK MARLIN 010			SHORT-NOSE MARLIN 107		
				No. Caught	Lbs. Caught	Value	No. Caught	Lbs. Caught	Value	No. Caught	Lbs. Caught	Value	No. Caught	Lbs. Caught	Value	No. Caught	Lbs. Caught	Value	No. Caught	Lbs. Caught	Value

Day of Landing	No. of Days at Sea	Area of Catch	Port of Landing	SILVER MARLIN 108			BROADBILL SWORDFISH 011			AU LEPE (Sailfish) 012			MAHIMAHI 013			ONO 014			OTHER (Give Name)*		
				No. Caught	Lbs. Caught	Value	No. Caught	Lbs. Caught	Value	No. Caught	Lbs. Caught	Value	No. Caught	Lbs. Caught	Value	No. Caught	Lbs. Caught	Value	Species Caught	Lbs. Caught	Value

BAIT REPORT

LOCAL BAIT						IMPORTED BAIT											
OPELU**			OTHERS			MACKEREL (Saba) 96		SMELT 97		SARDINE 94		HERRING 95		OTHER 92			
Date Caught	Pounds Caught	Locality Caught	Species Bought	Date	Lbs. Bought	Date	Lbs. Bought	Date	Lbs. Bought	Date	Lbs. Bought	Date	Lbs. Bought	Date	Lbs. Bought		

The reports contained hereon are true, correct, and complete to the best of my knowledge and belief.

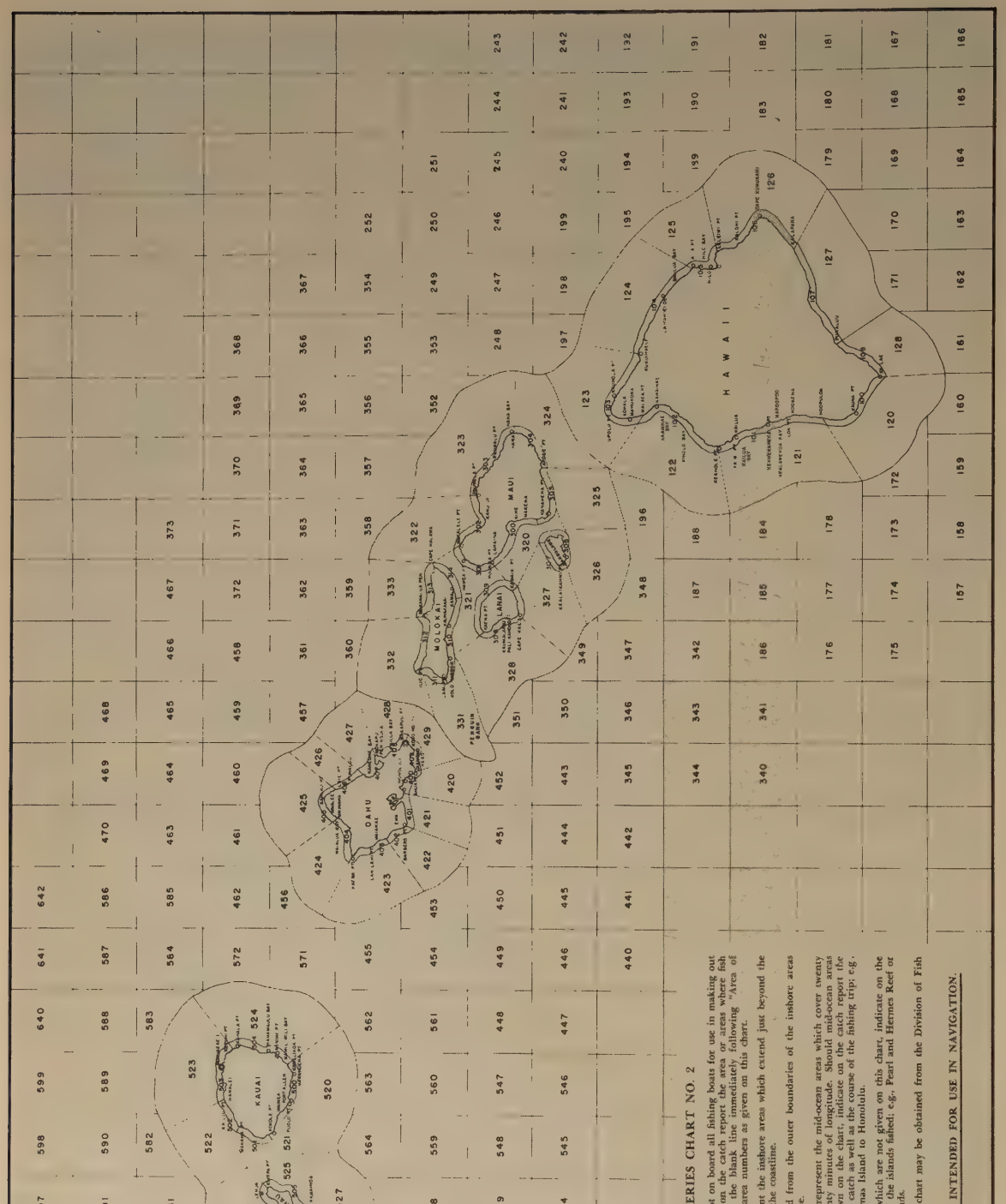
Signature

Permittee or Authorized Agent

* If several species are taken on a trip, which are listed under "other," skip that number of lines when entering catch report for next trip.

** If opelu purchased from other fishermen write in "bought under locality caught.

APPENDIX FIGURE 1.—Presently used longline (flagline) fish catch report form.


FISHERIES CHART NO. 2
This Chart should be kept on board all fishing boats for use in making out fish catch reports. Indicate on the catch report the area or areas where fish were caught by writing on the blank line immediately following "Area of Catch" the area number or area numbers as given on this chart.
The shaded areas represent the inshore areas which extend just beyond the reefs, roughly 2 miles from the coastline.
The offshore areas extend from the outer boundaries of the inshore areas to 20 miles from the coastline.
The blocks on the chart represent the mid-ocean areas which cover twenty minutes of latitude and twenty minutes of longitude. Should mid-ocean areas be fished which are not shown on the chart, indicate on the catch report the latitude and longitude of the catch as well as the course of the fishing trip; e.g., 14° N, 159° W. from Christmas Island to Honolulu.
Should islands be fished which are not given on this chart, indicate on the report the name of the islands fished; e.g., Pearl and Hermes Reef or Christmas and Fanning Islands.
Additional copies of this chart may be obtained from the Division of Fish and Game.
THIS CHART IS NOT INTENDED FOR USE IN NAVIGATION.
KAUAI
OAHU
MOLOKAI
LANAI
MAUI
HAWAII

APPENDIX FIGURE 2.—Hawaiian Division of Fish and Game fisheries chart No. 2, showing the statistical areas.

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DONALD W. STRASBURG

AN INSTANCE OF NATURAL MASS MORTALITY OF LARVAL FRIGATE MACKEREL IN THE HAWAIIAN ISLANDS

EXTRAIT DU JOURNAL DU CONSEIL INTERNATIONAL
POUR L'EXPLORATION DE LA MER
VOL. XXIV. No. 2. 1959

An Instance of Natural Mass Mortality of Larval Frigate Mackerel in the Hawaiian Islands

By

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Introduction

Mass mortality among larvae of the more fecund marine fishes has been commonly hypothesized but is poorly documented. Early workers ascribed a high death rate to the yolk-sac absorption stage (FABRE-DOMERGUE and BIÉTRIX, 1897; HJORT, 1914, 1926), but recent investigators have instead indicated a considerable mortality at the larva-postlarva transformation point (SETTE, 1943; MARR, 1956, on AHLSTROM and NAIR's MS.).

The existence of a critical period in the early life history has been discredited by AHLSTROM (1954), who states that the apparent mortality might be an artifact produced by net selection, and by MARR (1956), who presents a comprehensive review of the subject. MARR concludes that there is little evidence to support the critical period theory, that records of the natural occurrence of dead larvae may be artifacts, and that where mortalities are restricted in time the causes should be obvious. He qualifies this last idea by saying that "...the chances that the observer will make the right observations at the right time and the right place are greatly reduced".

This paper documents an apparently rarely observed phenomenon, the occurrence of large numbers of dead marine fish larvae. Because of the doubt which has been cast upon a natural mortality of this sort, and because of the slight chances for observing it, it is desirable to present detailed descriptions of the fish, the sampling methods, and the environment at the time of sampling. Particular attention has been paid to the question of whether the larvae were actually dead when collected.

Methods and Descriptions

During 1956 and 1957 the Pacific Oceanic Fishery Investigations (POFI), of the United States Fish and Wildlife Service, Honolulu, tested several types of plankton tows in an attempt to devise a standard method for sampling larval tuna. On 11–13. July 1957, the POFI vessel "Charles H. Gilbert" operated in

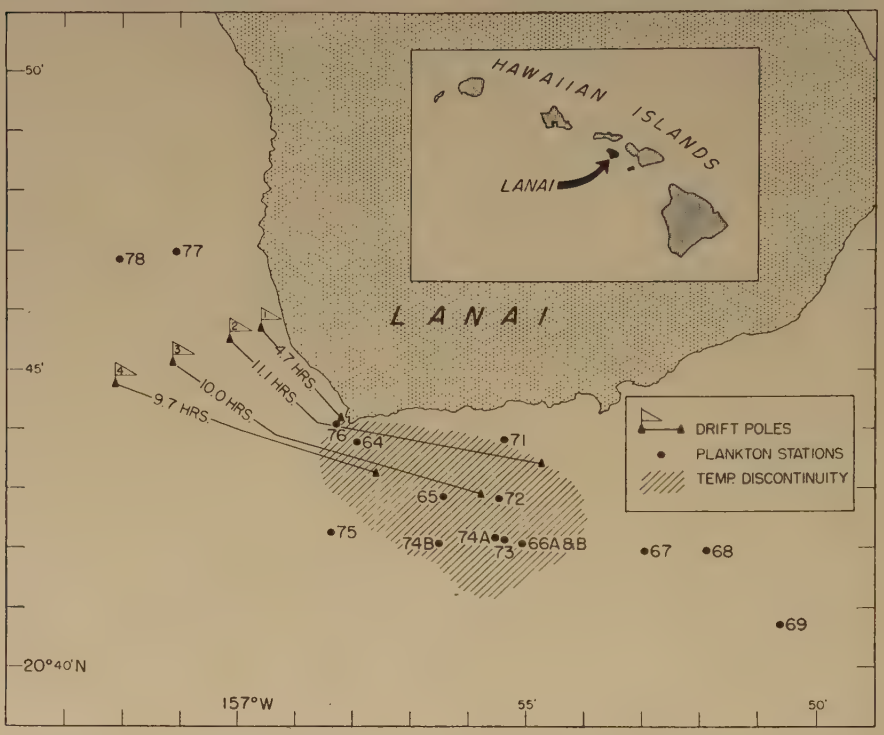

Figure 1. Lanai Island showing stations from which frigate mackerel larvae were obtained, tracks of driftpoles, and area of temperature discontinuity.

the vicinity of Lanai Island, one of the smaller members of the Hawaiian chain (Fig. 1). Here a series of half-hour plankton tows was made with a 1 m (mouth diameter) net, 5 m long and constructed of nylon gauze having mesh apertures 0·66 mm in width in the body of the net and 0·31 mm in the rear section and bag. Horizontal tows were made at the surface and oblique tows from the surface to about 60 m; in the former the net fished just beneath the surface, in the latter it was lowered and retrieved at a slow uniform rate. The vessel's speed was 2·5–3·5 knots during both tows, and the course pursued was frequently circular. A current meter in the net's mouth provided estimates of the volume of water strained. The stations, catches, and other data pertinent to these operations are summarized in Table 1.

At the end of each tow the net was rinsed with salt water to wash plankton residues into the bag. The plankton was immediately transferred to a glass jar and preserved in 10% borax-neutralized formalin. Fish and fish eggs were removed from the surface samples two weeks after collection, and from the 0–60 m samples six weeks after collection, and these were also stored in 10% neutralized formalin. At no time was there any evidence of putrefaction in the samples.

The larval scombrid fishes sorted from the collections were identified with the aid of MATSUMOTO's two recent papers (1958 and MS.), with the dominant

Table 1

Larval frigate mackerel, *Auxis* sp., captured off Lanai, 11–13. July 1957, in half-hour tows with a 1 m zooplankton net

Station	Depth (m)	Date	Time tow started	North latitude	West longitude	Number of larvae	Larvae per 1000 m³	Percentage dead larvae	Surface temp. °C	Invertebrate plankton (ml/1000 m³)
64	0	11	1924	20°43·8′	156°58·0′	77	30·8	6·5	26·6	18·5
65	0	11	2059	20°42·9′	156°56·5′	288	129·1	5·9	26·4	6·5
66A	0	11	2301	20°42·1′	156°55·1′	140	58·3	99·3	26·3	4·1
66B	0	11	2337	20°42·1′	156°55·1′	173	60·4	99·4	26·3	3·9
67	0	12	0100	20°42·0′	156°53·0′	96	41·5	18·8	26·2	5·7
68	0	12	0300	20°42·0′	156°51·9′	65	27·7	4·6	26·2	6·5
69	0	12	0501	20°40·7′	156°50·6′	210	117·6	96·2	26·2	25·5
71	0–54	12	2001	20°43·8′	156°55·4′	43	35·4	0·0	25·8	40·3
72	0	12	2046	20°42·8′	156°55·5′	1557	665·8	12·8[1])	26·5	12·4
73	0–59	12	2201	20°42·2′	156°55·5′	185	113·8	50·3	26·7	20·2
74A	0	12	2233	20°42·2′	156°55·6′	186	78·5	53·2	26·7	7·6
74B	0	12	2306	20°42·1′	156°56·6′	234	102·0	23·9	26·4	10·5
75	0–58	12	2349	20°42·4′	156°58·5′	6	3·4	16·7	26·3	18·0
76	0–62	13	0035	20°44·2′	156°58·3′	138	86·9	10·9	26·4	19·8
77	0–82	13	0133	20°47·2′	157°01·0′	30	20·9	6·7	26·2	27·8
78	0–77	13	0221	20°47·1′	157°02·0′	65	39·5	7·7	26·2	28·9

[1]) Based on a subsample of 635 fish.

form being frigate mackerel (*Auxis* sp.). The larvae of the two species of frigate mackerel occurring in Hawaii (*thazard* and a *thynnoides*-like form) are not as yet separable, and it is not known whether more than one species occurred in the Lanai collections. Not only were large numbers of frigate mackerel larvae obtained, but in many cases the specimens appeared to have been dead prior to capture. The correctness of this supposition is discussed in the following paragraphs.

Assessment of Mortality

When first examined the larval frigate mackerel were viewed against a black background with direct, overhead illumination. It was immediately noticeable that there were two distinct types: clean-cut larvae of normal appearance, and imperfect specimens with signs of physical deterioration. Further examination led to the hypothesis that these types represented fish which were alive and dead, respectively, just prior to capture. With this idea in mind all specimens were examined against a black background, and categorized as living or dead on the basis of the following characteristics: —

Living – flesh cream-coloured, opaque; vertebral column visible as a grey line separating epaxial and hypaxial musculature; visceral mass and anus turgid; eyes, jaws, and gill arches usually intact; body frequently contorted.

Dead – flesh grey, somewhat translucent; vertebral column invisible; visceral mass often lacking, when present both it and anus flabby; eyes typically absent; lower jaw prognathous; gill arches distorted; body straight.

Typical representatives of these two types are shown in Figure 2. The colour and transparency of the flesh of the "dead" fish suggest decomposition, as does the lack of eyes and distortion of the gill arches. However, the latter effects

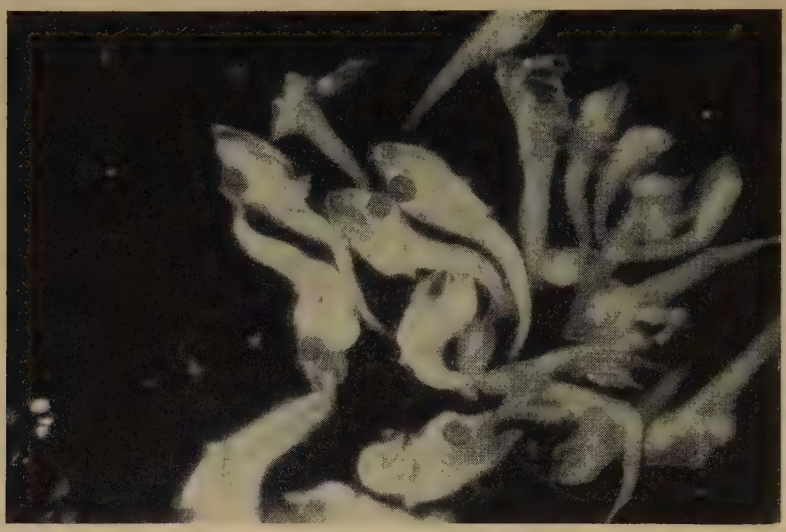

Figure 2. Typical larval frigate mackerel from Lanai. The light coloured specimens to the left were regarded as living, the darker fish to the right as dead.

could also be caused by net damage. The straightness of the body, which stands in marked contrast to the contorted attitudes of the most perfect and fresh looking larvae, implies considerable muscular relaxation, a phenomenon associated with death, at the time of preservation. The loss of the visceral mass could similarly be related to death and putrefaction, with the bloated viscera rupturing the body wall and ultimately tearing free. An increase in buoyancy, brought about by the accumulation of the gases of decay, is a logical mechanism by which dead larvae would remain at the surface to be collected. It should be noted that these larvae do not have swimbladders.

Before accepting the above hypothesis it is necessary to examine several possible causes for the condition of the damaged and "dead" larvae. MARR (1956) noted that damaged larvae were common in plankton samples containing hard, sharp animals such as pteropods, and that another common source was contamination from a previous haul owing to inadequate washing of the net. To investigate the damage caused by hard-bodied animals, counts were made of all pteropods occurring at Stations 66B and 71, where frigate mackerel mortality was 99·4 and 0·0%, respectively. The total number of pteropods was 22 for Station 66B, and 115 for Station 71, a reverse trend from what would be expected if pteropods damaged the larvae. Neither was damage proportional to the invertebrate plankton volumes obtained (Table 1), for no correlation was found when the plankton volumes were plotted against percentage mortality. It was concluded that the presence of other organisms in the catch had little to do with the condition of the larval frigate mackerel.

As stated earlier, the net was washed between tows so that few organisms could have persisted to contaminate later samples. Examination of the stations listed in Table 1 reveals that a catch showing a heavy mortality sometimes followed one of numerous normal fish, but that several stations were notably at variance with this. Thus Stations 66A and 66B were successive and had

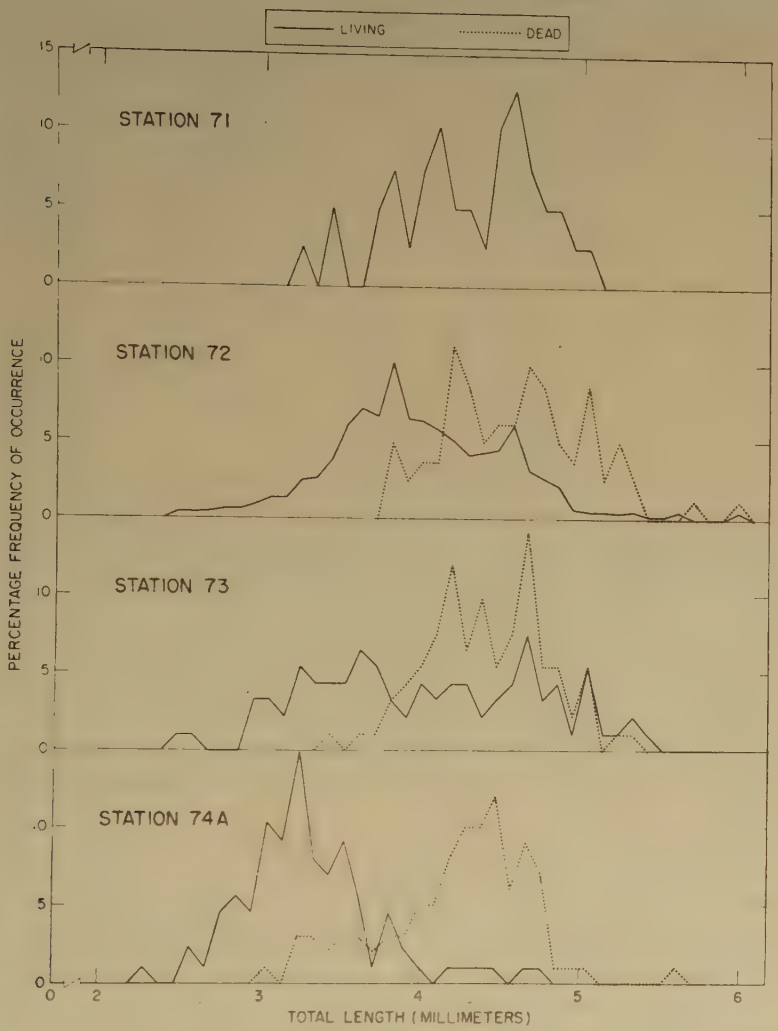

Figure 3. Length-frequency distribution of frigate mackerel at stations showing heavy mortality. Data derived from following numbers of fish: Station 71, 39 living; Station 72, 554 living, 81 dead; Station 73, 92 living, 92 dead; and Station 74A, 87 living, 99 dead.

equally high mortalities, as did Stations 73 and 74A, and Station 76 had an appreciable mortality, yet followed Station 75 where only 6 larvae were captured.

Another line of evidence tending to discredit contamination deals with the length-frequency distribution of the living and dead larvae. Here, total length was measured with the aid of an ocular micrometer, using the snout tip and the end of the longest caudal ray as reference points. Measurements were made to the nearest micrometer subdivision (0·095 mm) and subsequently converted to millimetres. Rather complete overlaps were found in length frequency for

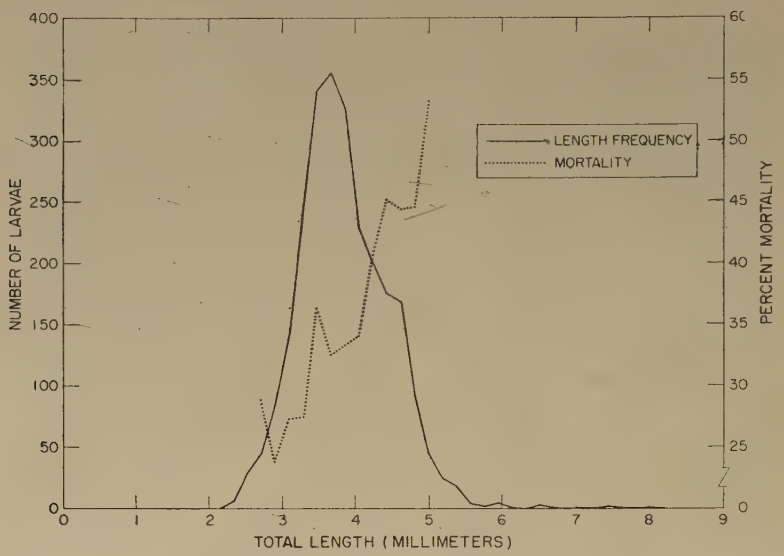

Figure 4. Length-frequency distribution of frigate mackerel, and percentage dead at various lengths. Length data derived from 2561 living and dead specimens; mortality figures based upon 2459 specimens.

Stations 64 through 69, but for Station 71 through 78 there was evidence that the dead fish were not from the same length populations as the living ones. Figure 3 shows that although the dead larvae taken at Station 72 could have been carry-overs from Station 71, there is little likelihood that those in Station 73 persisted from Station 72, or that those in Station 74 A were remnants from Station 73.

If the occurrence of the dead larvae was actually due to contamination then one would expect the mortality at a given length to be proportional to the number of fish of that length. That this is not so is shown by Figure 4, which depicts the mortality at each length category (a subsample was studied from Station 72, and mortality was not calculated for the smaller samples). Mortality is seen to increase with size, with fish about 5 mm in total length being most severely afflicted. As noted by STRASBURG (MS.), tuna larvae of 5 mm and larger are not often caught in plankton nets, probably because of their increased ability to avoid the net, so that their present capture may have been possible because they were dead.

A simple experiment was performed to determine if decomposing larval tuna would ultimately have the appearance of "dead" larvae. The plankton from several night surface tows was frozen after collection, thawed in the laboratory, and sorted in dishes placed in bowls of ice. Twenty-seven larval tuna (19 *Neothunnus macropterus*, 7 *Auxis* sp., and 1 *Katsuwonus pelamis*) were obtained, and these were examined and their appearance noted. Seven representative specimens were then preserved in formalin and the balance allowed to decompose in dishes of sea water over a period of nearly 47 hours at room temperatures of 23°–29°C. The decomposing specimens were re-examined at intervals and samples were preserved periodically. When all specimens had been preserved they were set aside for one week and then categorized as living or dead using

Table 2

Effects of decomposition upon appearance of larval tuna

Time sample preserved	Appearance of larvae (L = living, D = dead, L^1 and D^1 are intermediates)
10 min.....	4 L, 1 L^1, 1 D^1, 1 D
3 hr., 10 min.....	2 L, 2 D^1
6 hr., 45 min.....	2 D^1, 2 D
22 hr., 20 min.....	1 L^1, 3 D
30 hr., 55 min.....	1 L^1, 4 D*)
46 hr., 45 min.....	1 L, 2 D*)

*) Specimens badly deteriorated.

the criteria listed above. The effects of decomposition upon the appearance of these larvae are shown in Table 2 from which it is apparent that a "dead" appearance was generally acquired after 3–6 hours of decomposition. Some specimens, however, had a "living" aspect after 31 hours, and an unusually large fish (a 9·5 mm *Neothunnus macropterus*) appeared "living" after nearly 47 hours. Another larva appeared "dead" both at the start of the experiment and after a week in formalin.

Decomposition seems to be the agent responsible for the difference in appearance between the living and dead specimens. In this connexion it should be noted that decomposition in still water did not result in loss of the visceral mass, although it did cause a considerable loosening of that structure. Presumably the dead specimens taken at sea lost their viscera from agitation by waves or by the plankton net. It was also of interest that no experimental specimens bloated as decay progressed. This does not necessarily eliminate bloating-induced flotation as the mechanism responsible for dead larvae being caught at the surface, for apparently some fish decompose without rising to the surface (DENCE, 1956).

Causes of Death

In natural conditions an increase in the abundance of organisms is thought to be depressed by a system of checks and balances: predation, disease, competition, and the suitability of the physical environment. Predation can be excluded from the present case because it would have resulted in the recovery of no larvae or of larvae with some signs of natural mutilation. The agency involved instead appears to be generalized, for it afflicted a relatively wide size range of larvae, and was apparent over a distance of 12·5 miles and through a time interval of 29 hours.

Gross external examination of about 300 specimens (living and dead in about equal numbers) revealed no signs of disease, but it should be remembered that disease would not necessarily have external manifestations, and that slight symptoms could have been overlooked. No parasites were encountered on the gills, integument, or mouth surfaces, nor were any found internally.

About 500 living and dead larvae were examined for ingested food, with about 50 being dissected and the remainder viewed against a strong light which rendered them quite transparent. No food items were found in the digestive tract of any specimen, but in two cases the intestine was so bloated that the body wall bulged laterally, and when opened was found to be filled

with viscid white fluid. Those fish examined for the presence of food had been captured in the evening, at night, and at dawn, so that the lack of food in their stomachs may only mean that young frigate mackerel are daytime feeders. As can be seen from Table 1, no daytime samples were collected.

There is no way of determining if the mass death was caused by starvation. All specimens were past the "critical" period of yolk-sac absorption, and presumably had already begun feeding on planktonic food. Neither the type of food consumed nor its availability during the sampling period is known. There should be competition for food between individual frigate mackerel larvae and possibly also between them and various other members of the zooplankton. The invertebrate portion of the latter, however, was not over abundant in the samples collected, for the mean catch, 16·0 ml of plankton per 1000 m^3 of water strained was equal to, or less than, comparable Hawaiian plankton samples reported upon by KING and HIDA (1954, 1957). Thus if starvation were the cause of death it might have been induced by intra-specific competition or lack of a critical supply of the right sort of food.

POFI is continuing its studies of the Lanai area for several reasons, one of which concerns a water temperature discontinuity in the region from which the present samples came (Figure 1). In the discontinuity zone surface temperatures varied as much as 1·5°C in approximately one mile, and the surface was frequently characterized by floating terrestrial debris. As pointed out by MATSUMOTO (1958) and STRASBURG (MS.), larval frigate mackerel migrate to the surface at night, and would then be in a region of rapid temperature change at Lanai. Figure 1 also shows the discontinuity area to lie in the path of a current flowing south-easterly or easterly at a speed of about 0·5 knots.

It is to be noted that the upstream stations (Nos. 64, 65, 75–78) had frigate mackerel mortalities ranging only from 5·9 % to 16·7 %, whereas at certain downstream stations (Nos. 66A, 66B, 73–74B) mortality ranged from 23·9 to 99·4 %. Although not true of all stations, it would seem that passage through the discontinuity area was directly related to mortality.

The location of the principal death site can be roughly calculated by means of the known decomposition rate and current speed. A 0·5 knot current would flow 1·5–3 miles in the 3–6 hours necessary for larvae to assume a "dead" appearance by decomposition. In the case of the stations showing the heaviest mortality (Nos. 66A and B), this could place the death site at or near the north-western edge of the discontinuity area. Current drift could also account for the appearance of large numbers of dead larvae downstream from the discontinuity area (Station 69). The lack of high mortality at such stations as 67, 68, and 72 is presently inexplicable.

Summary

1. The mass death of larval marine fish has been the subject of much speculation but has remained largely undocumented. The present paper deals with a series of Hawaiian plankton samples containing 3,493 larval frigate mackerel (*Auxis* sp.), large numbers of which were thought to be dead before capture.

2. The appearance of the dead larvae was markedly different from that of the living fish, and these differences could logically be associated with death prior to capture. Deterioration of the dead fish was probably not brought

about by contact with hard, sharp organisms, or by the fish remaining in the net between hauls. The length-frequency distributions and the percentage mortality of various length groups also discredited contamination of this sort. Fresh larvae allowed to decompose attained a "dead" appearance in from 3 to 6 hours.

3. The definitive cause of death could not be determined. There were no signs of predation, disease, or parasitism, but starvation could not be definitely excluded as a factor. It was tentatively hypothesized that the mass death was brought about by passage through an area having marked discontinuities in its surface water temperature.

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Reprinted from COPEIA, 1959, No. 3, pp. 244-248, October 9
Printed in U. S. A.

NOTES ON THE DIET AND CORRELATING STRUCTURES OF SOME CENTRAL PACIFIC ECHENEID FISHES.—Although the results of a stomach analysis of echeneid fishes have existed in the literature for over 100 years they have been largely overlooked by ichthyologists. Thus Bennett's (*Narrative of a whaling voyage . . . 2:271,* 1840) finding of ". . . small marine insects, shrimps, and fragments of delicate shells" in the stomachs of *Remora remora* is not widely known, and the food of this and related species is instead generally described as scraps from the meals of its hosts (sharks, marlin, sea turtles, etc.).

While the relation between an echeneid and a larger animal has become almost a classic example of commensalism, it is not clear with whom the idea originated. It was frequently mentioned at the turn of the century (Holder, *Sci. Amer. 82(21):331,* 1900; *ibid. 93(9):163,* 1905; Geare, *ibid. 87(5):73,* 1902) and has persisted until the present (Irvine, *The fishes and fisheries of the Gold Coast, pp. 211–2,* 1947; Norman, *A history of fishes, pp. 70,245–46,* 1949; Norman and Fraser *Field book of giant fishes, p. 176,* 1949; Smith, *The sea fishes of southern Africa, p. 340,* 1950; Bigelow and Schroeder, *USFW Serv. Fish. Bull. 53(74):484, 487,* 1953). Some of the above authors as well as Jordon (*Fishes, p. 679,* 1907) and Boulenger (*Teleostei, Cambr. Nat. Hist. 7:691,* 1922) state that echeneids are also carnivorous upon small fish such as sardines and herring; in this case the hosts merely serve for transportation to the feeding grounds at which the echeneids detach and actively pursue their prey. Smith (*op. cit.*) cites an earlier worker's observation (?) of echeneids consuming the hosts' faeces as a major dietary item.

Two recent papers suggest that the principal fare of echeneids may be entirely different from the foods suggested above. Szidat and Nani (*Rev. Inst. Invest. Mus. argent. Cienc. nat. 2(6):413,* 1951) observed the ectoparasitic caligid copepods *Achteninus* and *Pandarus* in the stomach of *R. remora,* and Maul (*Bol. Mus. Funchal 9:14,* 1956) found both caligid copepods and oxycephalid amphipods in this species. In addition, Maul discovered the planktonic heteropod *Atlanta* in the digestive tract of *Remoropsis brachypterus.* These authors postulate that echeneids and their hosts are symbionts, with the echeneid's function being parasite removal and consumption. Similar arrangements exist in birds which clean the hides and mouths of large reptiles and pachyderms, and also between wrasses of the genus *Labroides* and many other fishes (Randall, *Pacific Sci. 12(4):327–347,* 1958). Neither Szidat and Nani nor Maul had adequate specimens to depict the extent of parasite-feeding in the Echeneidae, and the present paper was prepared to illustrate the dietary trends apparent in several genera and species. The specimens studied are presently in the collections of the U. S. Fish and Wildlife Service, Honolulu.

Material examined.—Identification of echeneids was made with the aid of the keys of Maul (1956) and Schultz (*U. S. Nat. Mus. Bull. 180:256,* 1943), with the following species being present: *Rhombochirus osteochir* (Cuvier), *Remora remora* (Linnaeus), *Phtheirichthys lineatus* (Menzies), *Remoropsis pallidus* (Schlegel), and *Remoropsis brachypterus* (Lowe). In addition to meristic and morphometric characters, identication was also based upon the stained lateral-line scales, as illustrated by Maul. Some difficulty was experienced in distinguishing the species of *Remoropsis,* for in addition to specimens with the respective color patterns and scales of *pallidus* and *brachypterus,* there were others with *pallidus* coloration but *brachypterus* squamation. Scales were considered the more reliable criterion in such cases, and these specimens were labeled *brachypterus.* Szidat and Nani (1951) were followed in synonymizing *Phtheirichthys multiradiatus* Schultz with *P. lineatus* (Menzies). A summary of the data accompanying the specimens is presented in Table 1.

Viscera.—The digestive tracts were removed while the fish were soaking in water preparatory to transfer from formalin to alcohol. In no case were there evident any signs of improper preservation.

Two types of internal anatomy were encountered among the five species examined. In the first, typified by *Rhombochirus, Remora,* and *Phtheirichthys,* the digestive tract consisted of a short esophagus, a muscular J- or Y-shaped stomach, 4–7 large pyloric caeca, and a long, coiled intestine divided into anterior and posterior portions by a valvular fold. Both regions of the intestine were densely papillate internally in all species, but the intestinal length varied from 130 percent of the standard length in *Rhombochirus* to 40–60 percent of the standard length in *Remora* and *Phtheirichthys.* The smallest specimens of the latter genera had poorly differentiated viscera, the tract often appearing as a simple straight tube, which was internally papillate, from mouth to anus. No dietary dif-

TABLE 1

ECHENEID FISHES EXAMINED FOR FOOD

Species	Date	Latitude	Longitude	Sex	Standard length (mm.)	Host
Rhombochirus osteochir	7/20/50	05°42′N	171°54′W	F	161	*Makaira audax*
	?	North	Pacific Ocean	F	218	?
	8/30/56	09°32′S	136°55′W	M	240	*Makaira ampla*
	8/30/56	09°32′S	136°55′W	F	282	*Makaira ampla*
Remora remora	8/30/56	09°32′S	136°55 W	?	52	Attached to longline buoy
	2/10/56	21°23′N	158°29′W	M	84	*Pterolamiops longimanus*
	2/10/56	21°23′N	158°29′W	?	108	*Pterolamiops longimanus*
	8/21/52	07°02′N	140°46′W	M	131	*Pterolamiops longimanus*
	9/3/56	10°25′S	139°40′W	F	134	*Pterolamiops longimanus*
	3/18/56	00°11′N	139°53′W	M	154	*Pterolamiops longimanus*
	8/7/57	36°45′N	124°34′W	F	235	*Prionace glauca*
Phtheirichthys lineatus	8/27/56	12°16′S	133°20′W	?	44	Attached to longline bait (herring)
	8/28/56	11°23′S	134°32′W	?	46	In stomach of *Neothunnus macropterus*
	8/26/56	13°26′S	132°16′W	?	54	Attached to longline buoy
	9/29/51	21°24′N	158°15′W	F	300	Dipnetted beneath night-light
Remoropsis pallidus	9/1/56	07°30′S	138°57′W	F	119	*Makaira audax*
	8/21/52	07°02′N	140°46′W	F	126	*Makaira ampla*
	8/28/52	01°00′N	140°22′W	M	130	*Istiompax marlina*
	8/19/56	02°42′S	131°42′W	M	139	*M. ampla* or *I. marlina*
	9/1/56	07°30′S	138°57′W	M	148	*Makaira audax*
	8/19/56	02°42′S	131°42′W	M	167	*M. ampla* or *I. marlina*
	4/4/55	01°49′N	157°38′W	F	179	*Istiompax marlina*
	4/4/55	01°49′N	157°38′W	F	184	*Istiompax marlina*
	9/1/56	07°30′S	138°57′W	F	186	*Makaira audax*
Remoropsis brachypterus	8/19/56	02°42′S	131°42′W	?	53	*M. ampla* or *I. marlina*
	9/1/56	07°30′S	138°57′W	F	81	*Makaira audax*
	8/19/56	02°42′S	131°42′W	F	107	*M. ampla* or *I. marlina*
	8/19/56	02°42′S	131°42′W	F	110	*M. ampla* or *I. marlina*
	8/30/56	09°32′S	136°55′W	F	119	*Makaira audax*
	4/15/54	01°58′N	155°16′W	M	136	*Istiompax marlina*
	8/19/56	02°42′S	131°42′W	F	167	*M. ampla* or *I. marlina*
	8/18/56	00°57′S	132°24′W	F	197	*Istiompax marlina*

ferences were noted between small and large *Remora* or *Phtheirichthys*.

The second type of visceral anatomy occurred in *Remoropsis*, and resembled the juvenile condition of the other genera. The stomach and pyloric caeca were ill-defined or lacking so that the digestive tract was a straight papillate tube as shown by Suyehiro (*Jap. Jour. Zool. 10(1):217*, 1942). In this connection, we were unable to find the liver-like caecal mass noted by Suyehiro. Pyloric caeca were either absent or, in the largest specimens, occurred as a series of short evaginations arranged radially posterior to a diminutive stomach. Again no differences in food habits were detectable between specimens with and without caeca and stomachs.

Results of the food study.—Table 2 summarizes the occurrence of food material in the digestive tracts of each species. At this time I should like to acknowledge my indebtedness to Mr. Everet C. Jones, U. S. Fish and Wildlife Service, Honolulu, for identifying most of the invertebrate food organisms. The foods were grouped by categories suggestive of the following feeding methods: plankton feeding, preying upon ectoparasites and other attached organisms, and consumption of scraps. This classification is arbitrary in that it was not known whether certain crustaceans were attached or free-swimming, and also in that the source of the scraps could not be determined. Conceivably, scraps could represent remnants of the host's meal, portions of large prey captured by the echeneid itself, fragments of bait used to capture the host, table scraps from the fishing vessel, or undigested material from the host's faeces. Despite these vagaries the data fall into several patterns as discussed below.

All species except *R. brachypterus* consumed some food in the scrap category. In most cases individuals doing this were outnumbered by those taking other food, and scrap consumption

TABLE 2

ITEMS FOUND IN THE DIGESTIVE TRACTS OF ECHENEID FISHES. FIGURES REPRESENT NUMBER OF FISH CONSUMING THE ITEM

Food item	*R. osteochir*	*R. remora*	*P. lineatus*	*R. pallidus*	*R. brachypterus*
Planktonic organisms					
Amphipoda, hyperiids	—	3	1	1	2
Amphipoda, unidentified	—	—	1	—	1
Decapoda, *Lucifer* sp.	—	1	—	—	—
Decapoda, crab zoea	—	1	1	—	—
Decapoda, unidentified larvae	—	2	—	—	1
Copepoda (calanoid), *Candacia pachydactyla*	—	1	—	—	—
Copepoda (calanoid), *Candacia aethiopica*	—	1	1	—	—
Copepoda (calanoid), *Candacia* sp.	—	—	1	—	—
Copepoda (calanoid), *Scolecithrix* sp.	—	1	—	—	—
Copepoda (calanoid), unidentified	—	1	2	—	—
Copepoda (harpacticoid), *Sapphirina* sp.	—	1	—	—	—
Copepoda (harpacticoid), *Oncaea* sp.	—	—	1	—	—
Stomatopoda, larvae	—	1	1	—	—
Euphausiacea	—	2	1	—	—
Mysidacea	—	1	—	—	—
Ostracoda	—	—	1	—	—
Crustacea, unidentified fragments	—	1	—	—	—
Mollusca (heteropod), *Atlanta* sp.	—	—	—	—	1
Mollusca (pteropod), *Cavolinia tridentata*	—	—	—	—	1
Fish, *Ranzania* sp. juveniles	—	2	—	—	—
Fish, *Gnathanodon* sp. juveniles	—	1	—	—	—
Fish, unidentified larvae and juveniles	—	2	—	—	—
Fish, unidentified bones	—	—	1	—	—
Fish, unidentified scales	—	3	—	—	—
Parasitic or attached organisms					
Copepoda (caligoid), *Nesippus* sp.	—	—	—	—	1
Copepoda (caligoid), *Gloiopotes* sp.	—	—	—	2	—
Copepoda (caligoid), pandarid	—	—	—	1	—
Copepoda (caligoid), caligid	—	—	—	1	—
Fish, unidentified echeneid	—	—	—	—	1
Scraps					
Fish muscle or liver	1	—	—	2	—
Unidentified muscle	—	—	1	—	—
Squid skin (?)	—	—	—	1	—
Grapefruit fragments	—	1	—	—	—
Meat from galley	—	1	—	—	—
Empty	3	1	0	3	3
Total examined	4	7	4	9	8

is therefore probably opportunistic rather than a regular way of life. Little can be said of the incidence of scrap consumption in *Rhombochirus.*

Miscellaneous adaptations.—In addition to the differences in viscera and diet discussed above, two other aspects of echeneid biology were investigated. The first concerns the manner by which the parasite-feeding species obtain their prey, in brief, whether they are structurally modified for capturing the flattened, clinging "sea-lice" upon which they feed. In all species examined, the lower jaw projects beyond the upper so that its short canine and villiform teeth enter the snout profile (see Suyehiro 1942:217). A measure of the degree of prognathism was obtained by dividing the distance between the tips of the two jaws by the snout length. Excluding specimens shorter than 100 mm. (which all had greatly projecting lower jaws) this overbite averages 28 percent for *Remoropsis pallidus,* 25 percent for *Remoropsis brachypterus,* 17 percent for *Remora remora* and *Phtheirichthys lineatus,* and 12 percent for *Rhombochirus osteochir.* Not only does *Remoropsis* have from 50–100 percent greater overbite than the other genera, but its teeth are also longer and could seemingly be brought to bear on the host's skin while attached by the sucker. It is thus conceivable that these fish obtain their parasitic food while attached to the skin of the host.

Fish and invertebrate plankton constituted the principal diet of *R. remora, P. lineatus,* and to a lesser extent, *R. brachypterus.* In several cases individuals were found with the alimentary tract crammed with one or two planktonic species indicating either selectivity in feeding or patchy distribution of plankters. As is shown in Table 2, *R. brachypterus* also fed upon ectoparasites, and Szidat and Nani (1951) and Maul (1956) found *R. remora* doing the same. These two species may be transitional with respect to diet, feeding upon plankton when it is abundant and taking parasites at other times. No ectoparasites were found in *P. lineatus,* but to this should be added the fact that none of the present specimens was attached to a living fish (Table 1). Of the two fish removed from longline buoys, the *R. remora* had an empty digestive tract whereas the *P. lineatus* had consumed a variety of planktonic organisms as well as scraps. The *P. lineatus* taken from a longline bait contained a single hyperiid amphipod.

Remoropsis pallidus is apparently largely dependent upon its hosts' ectoparasites as food, and as noted above, it may also feed upon remnants of its hosts' meals. Its lack of dark pigment and its propensity for dwelling in the branchial cavities of marlin are undoubtedly additional modifications towards a highly specialized existence. Perhaps echeneids tend to invade the bucco-pharyngeal regions of their hosts because of a concentration of parasites there; a similar explanation has been offered by Szidat and Nani (1951) to account for echeneids' temerity around the mouths of sharks.

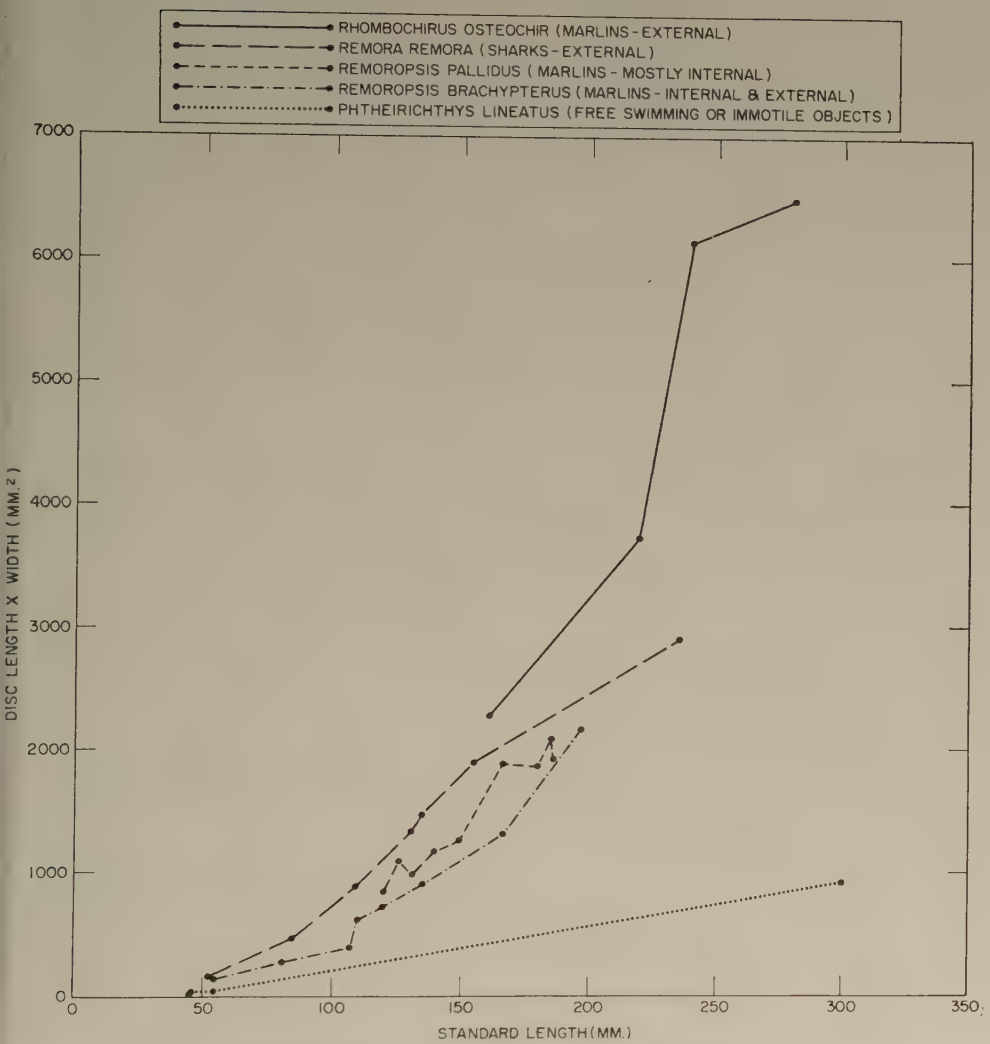

Fig. 1.—Echeneid disc size versus fish length and type of attachment to host.

It is difficult to relate the difference in viscera with that in diet between the plankton- and parasite-feeding species.

It will be noted from Table 1 that some echeneids were more or less host-specific, and the second question deals with structural modifications relating to this. The feature investigated was the sucking disc, with an attempt being made to relate its area to the type of host or attachment site. An approximation of the area of the elliptical sucker was obtained by multiplying its greatest length by its greatest width. Areas obtained in this way have been plotted against fish length in Figure 1. It can be seen that the fish with the largest sucker, *Rhombochirus,* attaches to the body skin of fast swimming marlins, whereas the one with the smallest sucking disc, *Phtheirichthys,* is free-swimming or attached to immotile objects (it is also known from barracuda and sea bass—Schultz, 1943; Smith, 1950). Species intermediate in sucker-size attach to relatively slow-swimming sharks or take refuge beneath the opercula of marlins. Presumably water flow and turbulence are less in the branchial cavity than on the outside of these hosts.

From the above discussion it is apparent that echeneids occupy at least three ecological niches. They are predators on zooplankton and the smaller nekton, commensals taking scraps from their host, and symbionts removing the host's parasites as food. These trends appear to have some systematic basis for they are reflected in morphology, host selectivity, and the attachment

site. The five species considered constitute a natural series ranging from the least host-dependent species to the most. At the primitive end of the scale is *Phtheirichthys lineatus*, and at the specialized end, *Remoropsis pallidus*. *Rhombochirus osteochir*, *Remora remora* and *Remoropsis brachypterus* are intermediates, with the first showing specialization in its ability to adhere, and the other two in tending toward parasite consumption.—Donald W. Strasburg, *U. S. Fish and Wildlife Service, Bureau of Commercial Fisheries, Honolulu, Hawaii.*

DISPLAY COPY

4. Underwater Observations on the Behavior of Hawaiian Tuna

The oceanic skipjack or aku (*Katsuwonus pelamis*) ubject to a considerable fishery in Hawaii, Japan, the continental United States. Because this tuna aught by chumming with live bait, and because is delicate and in short supply, the yield and fit of the fishery are not as great as warranted world demands. The Pacific Oceanic Fishery In- igations is attempting to increase the efficiency, hence the yield and profit, of live-bait fishing studying skipjack behavior as it is related to ral fishing variables.

This study has been conducted from the research el "Charles H. Gilbert," which is equipped with underwater observation chamber. Through this mber movies were taken of skipjack behavior er normal and experimental fishing conditions. As pplement to the movies, comments of underwater surface observers were recorded, along with rded bell tones denoting catch rate. The ob- ation chamber had three months of use during 8, a poor year for the Hawaiian fishery, during ch observational techniques were developed while eriments were conducted. The experimental re- s, although encouraging, are only tentative.

Several experiments involved the effects of varia- s in chumming on skipjack behavior. When live dead nehu (*Stolephorus purpureus*) were chum- alternately, the use of dead bait resulted in jack decreasing their swimming speed and num- of surface dashes, and also in falling so far rn that fishing ceased. When the rate of chum- g was doubled, more nehu accumulated than d be eaten by a small tuna school, again causing the tuna to fall behind. This did not apply to large schools, for these consumed the bait as rapidly as it was thrown. With the chumming rate halved, the tuna slowed their swimming and tended to scatter, no doubt as a result of an insufficient feeding stimulus. When water sprays were turned on and off at intervals, the "off" condition resulted in speed-slackening, reduction in the number of surface dashes, and deeper swimming, again reflecting inadequate feeding stimulation. Experiments in which nehu were replaced by threadfin shad (*Dorosoma petenensis*) showed that a too-conspicuous or too-active bait also resulted in a reduced catch.

Four other experiments dealt with rather extrinsic fishing variables. Noise produced by hammering on the ship's hull had no effects on behavior, nor did blood sprayed in the water or allowed to drain from the deck. Skipjack skin extracts thought to contain fright-producing purines or pterines similarly produced no visible response. When red food coloring was sprayed into the sea in dense concentrations, skipjack avoided any deeply stained masses of water, suggesting that perhaps they can be corralled by walls of sufficiently dark dye.

As more is learned about bait-skipjack interactions it becomes easier to select better bait species and lures and to modify existing fishing practices. The results of such tests as the dye experiments may lead to entirely new fishing methods.

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Reprinted from
PROCEEDINGS OF THE HAWAIIAN ACADEMY OF SCIENCE
Thirty-Fourth Annual Meeting • 1958-1959

Reprinted from the book MODERN FISHING GEAR OF THE WORLD, *published April, 1959, pages 538-542.*

Section 12 : Attraction of Fish.

SUMMARY OF EXPERIMENTS ON THE RESPONSE OF TUNA TO STIMULI

by

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Abstract

The aim of the experiments described in this paper was to obtain information which might lead to improved methods of tuna fishing, and especially in finding a substitute for baitfish. In a series of tank experiments, it was found that yellowfin and little tunny responded to white light of moderate intensity but not to a weak light. Their reactions to chemical stimuli were also observed and a positive response was obtained by using clear aqueous or alcohol extracts of tuna flesh. They were repelled, however, by copper acetate—the shark repellent. The possibility of electrofishing for surface tuna was investigated and since it was demonstrated that electrotaxis could be induced in tuna with an electric field of known characteristics, the problem becomes one of electrical engineering rather than of biology.

Résumé des expériences relatives à la réaction du thon aux stimuli

Résumé

Les expériences décrites dans cet article avaient pour but de recueillir des renseignements susceptibles de conduire à l'amélioration des méthodes de pêche au thon, et plus particulièrement de trouver le moyen de remplacer l'appât vivant. An cours d'une série d'essais en bassin, on a observé que les thons à nageoires jaunes et les "little tunny" (*Euthynnus yaito*) réagissaient à une lumière blanche d'intensité modérée mais non à une lumière faible. On a également observé leur comportement aux stimuli chimiques et l'on a obtenu une réaction positive par l'emploi d'extraits aqueux ou alcooliques de chair de thon. Toutefois, l'acétate de cuivre, utilisé pour écarter les requins, les a éloignés. La possibilité de pêcher les thons de surface à l'électricité a été étudiée, et comme il a été démontré que l'on pouvait provoquer l'électrotaxie chez le thon au moyen d'un champ électrique de caractéristiques connues, le problème relève plus de la technique de l'électricité que de la biologie.

Resumen de los experimentos sobre la reacción del atún a los estímulos

Extracto

Los experimentos descritos en este trabajo tuvieron por objeto reunir información para encontrar métodos mejorados de pesca de atún y, especialmente, un sustitutivó del cebo vivo. En una serie de experimentos en estanques se encontró que el atún de aleta amarilla y el atunito reaccionaban bien a la luz blanca de intensidad moderada pero no así a una débil. Además se observó el efecto de las substancias químicas lográndose una reacción al usar extractos acuosos o alcohólicos transparentes de carne de atún. Sin embargo los peces se alejaron al utilizar acetato de cobre que se utiliza para repeler a los tiburones. También se investigó la posibilidad de emplear la electricidad para la captura de los peces que nadan en la superficie, demostrándose que es posible producir la electrotaxia en el atún mediante un campo eléctrico de características conocidas, pero este problema cae más bien dentro del terreno de la ingeniería eléctrica que de la biología.

DURING the period 1951 and 1956, several staff members of the University of Hawaii conducted experiments, under contract with the Pacific Oceanic Fishery Investigations (POFI) of the U.S. Fish and Wildlife Service, on the response of tuna to various types of stimuli. The writer was leader of several of these projects prior to joining the Service in 1955. This is a brief summary of the work to date.

The primary objective of the study was to obtain information which might suggest new or improved methods of tuna fishing. Efforts were directed particularly at devising a substitute for baitfish, the scarcity and high mortality of which limits the catch of surface tuna in Hawaii and prevents the expansion of the live-bait fishery to potentially productive offshore areas.

ESTABLISHING TUNA IN CAPTIVITY

Methods of fishing, transporting and establishing tuna in captivity are described by Tester[6]. Several species of tuna and tuna-like fish were caught by surface trolling off the windward shore of Oahu, including the skipjack (*Katsuwonus pelamis*), yellowfin (*Neothunnus macropterus*), and little tunny (*Euthynnus yaito*). Immediately after capture, fish were placed in the vessel's livewell ($67\frac{1}{2} \times 43 \times 32$ in.), which was supplied with running sea water (20 to 40 gallons/min.) but which, in addition, was aerated with finely-divided bubbles of oxygen from a pressure tank. They were then transported to ponds and tanks at the Hawaii Marine Laboratory (1 to 2 hours run), to which they were transferred by dipnet. Yellowfin (about 2 to 8 lb. in weight) and little tunny (about 1 to 6 lb. in weight) were successfully established in one of the large ponds (350 ft. long, 65 ft. wide and averaging about 6 ft. deep) which was flushed by tidal currents. Yellowfin and little tunny were also maintained in a concrete tank (35 ft. long, 11 ft. wide and 4 ft. deep) which was supplied with running salt water (about 25 gallons/min.). Skipjack were not successfully established;

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of numerous trials only one fish was transported alive from the fishing grounds to the laboratory and it died shortly after being released into the tank.

Except when on an experimental diet, the little tunny and yellowfin were fed cut-up fish, usually small tuna which died during our fishing operations or large tuna from POFI longline catches. The tunas generally started to feed within a week of introduction; otherwise they would die. When feeding fish were already present in the pond or tank, newly introduced fish would usually join the school and start to feed within one or two days.

The established (feeding) tuna survived for various lengths of time, ranging from but a few days to over 2 years. Some loss occurred from extraneous factors such as poaching or accidental stranding of the fish on dry land. Several of the fish developed partial or complete blindness and died either from starvation or injury. Others eventually became "sick", they moved slowly, listlessly and individually, ceasing to feed and eventually dying. Mortality occurred mostly during the fall and winter, and perhaps was associated with lowered temperature and salinity in the inshore environment.

Yellowfin, both in the live well of the boat and in the pond and tank, were relatively slow, leisurely swimmers. When two fish were present, they usually swam together. When several were present, they formed a loose school but often swam individually or in two's or three's. In contrast, the little tunny were rapid swimmers and usually formed a single, compact school. On occasions, when a large population (15 to 30 fish) was present in the pond, they formed two schools, but rarely more.

More detailed observations on the captive fish are included in the papers summarized below.

RESPONSE TO VISUAL STIMULI

During the summer of 1951, Hsiao[1] studied the response of two yellowfin and five little tunny to artificial light. The fish were confined in the concrete tank. The experiments were performed after dark, with the tank illuminated constantly with two 60 W. bulbs. He found that both yellowfin and little tunny were attracted to continuous white light over a range of moderate intensity (about 70 to 450 ft. candles). They were not attracted by a light of weaker intensity, and they were repelled by a light of stronger intensity. Both species were attracted to coloured lights of moderate intensity, but to no greater extent than to white light. Similar results were obtained with interrupted white light. There appeared to be no relationship between the strength of the response and the frequency of interruption of the light. Although the tuna approached an interrupted light of moderate intensity, they were repelled from the near vicinity at the instant the light flashed either on or off.

The above experiments suggest that tuna at sea might respond to continuous light of moderate intensity. To my knowledge, however, only tuna larvae and young have been caught by this method. If adults in their natural habitat were attracted by light, it seems likely that this already would have been discovered and utilized by tuna fishermen.

The response of a school of 12 captive little tunny to moving objects of various colours in the large pond was studied by Hsiao and Tester[2] during the summer of 1952. During daylight hours, a pair of lures was momentarily dipped into an "attraction" area once every 2 sec. by a remote control from a high tower. The lures consisted of 2 in. sections of rubber tubing of various colours. The number of "fish-seconds" in the area, the number of "passes" at the lures, and the time were recorded on a kymograph. Observations were made under control conditions, when lures were introduced, and when lures were used along with an extract of tuna flesh (see later) which was introduced into the pond from one end. Activity of the fish (number of school entrances, time spent in the area, and swimming speed) was greater when lures were used, as compared with control conditions, and was still greater when lures and extract were used together. Although, in general, the fish made more passes at white than at coloured lures (red, black, silver), the superiority of the white lures was slight. It may have been associated with greater visibility rather than colour preference. There is no assurance that white lures would be superior to coloured lures in the open ocean. Trolling data collected during 1951 and 1953 (Tester and Nakamura[9]) show no preference by the tuna with respect to either form or colour of the lure.

The above experiments deal with only one aspect of visual response, namely lure preference. Specific pond experiments on visual acuity were not undertaken. Casual observations indicated, however, that both yellowfin and little tunny could perceive objects such as stones or pieces of food which were thrown to them while the objects were still in the air. The fish would speed rapidly toward the point where such objects would hit the water. If the objects were not thrown so that the fish could see them in transit, the tuna could be attracted either by the splash made when the object hit the water, or perhaps by the object itself over a distance of about 50 ft.

In view of the conclusion (see later) that visual perception was of prime importance in attracting tuna to the stern of a fishing boat by the use of livebait, Matthews[3,a] studied the comparative morphology of tuna eyes, during 1955-56, using species of diverse habits and habitats (skipjack, yellowfin, and bigeye). No significant differences were observed. In addition, he conducted experiments to determine the focal length of the lens and other optical properties of the excised eyes of freshly-killed tuna immersed in a long salt trough, viewing a light source through a "window" in the chorion of the vitreous chamber, but with confusing results (unpublished). Contract work in 1956-57 was devoted to a study of the comparative histology of the retina in skipjack, yellowfin, bigeye, and albacore, including observations on the frequency and arrangement of the rod-cone mosaics. Preliminary results[3,b] indicate a relatively large number of rods in the retina of the albacore, suggesting relatively greater adaptation to dim light than with the other three species.

RESPONSE TO AUDITORY STIMULI

Miyake[4] conducted experiments with captive yellowfin and little tunny during 1951-52 to discover (1) if tuna

produced any sound and (2) if they could be attracted or repelled by sounds of various frequencies. Using a listening frequency ranging from about 0·1 to 70 kc., he was able to identify low frequency sounds produced by the sudden movement of the tail of the yellowfin in the tank. This might have some significance with respect to the mechanism of school formation. No sounds produced by tuna were detected at listening frequencies in the moderate, high, or supersonic range. In attempting to attract or repel tuna by continuous sound stimulation in the pond, sounds were emitted at many frequencies from 0·1 to 70 kc. Although the results were inconclusive, there were indications that yellowfin might be attracted by complex sounds of low frequency.

RESPONSE TO CHEMICAL STIMULI

Van Weel[12] studied chemoreception in both yellowfin and little tunny in the concrete tank during 1951. He found that both fish had a well-developed sense of smell or taste whereby they were attracted to certain food substances. They were strongly attracted to clear, colourless extracts of tuna flesh. Moreover, it was found that the attractant was contained in the *protein* rather than in the *fat* fraction of the clear extract. In general, the response of the little tunny was more pronounced than that of the yellowfin. On the other hand, there was no positive response of either species to *conditioned* water in which baitfish had been living, nor to extracts of either baitfish or squid. Copper acetate, a shark repellent, was also repellent to tuna, although its effect was not as pronounced as on fish of other species which were also present in the tank.

The above study was continued in 1952-53 by Tester, Van Weel, and Naughton[10]. In the tank, improvements were made in the techniques of observation, introduction of test material, and measurement of the response. Testing was hampered by accumulation of test materials because of the small volume of water in the tank and its slow replacement. This problem was reduced by conducting tests on tuna established in the large pond, introducing test material through a continuous stream of water supplied at one end of the pond by a pump, and observing the response of the fish from a 20 ft. tower, which overlooked an "attraction" area extending from about 40 to about 80 ft. below the outlet. Pond testing was hampered by such factors as poor visibility due to weather, power failure, and erratic behaviour of the fish.

The results confirmed Van Weel's[12] observations that a positive response was obtained from clear, aqueous or alcohol extracts of tuna flesh. This took the form of a feeding reaction and included one or more of the following components: speeding or acceleration of the swimming rate, a return to the area of stimulation, surfacing, fanning-out and eventually a breakdown of school formation, circling, splashing, and biting at incidental objects on the surface of the water. It was postulated that an attractant was present in the flesh, viscera and blood of several species of tuna and certain other fish. Successful methods of concentration and preservation of this substance were achieved in preparation for large-scale sea-testing. Considerable time was devoted to its fractionation, purification, and identification.

In addition some 40 chemical compounds were tested, including amino acids, vitamins, aromatics, proteins, etc. With some of these there seemed to be a sensing of the dissolved or suspended materials but in no case did the response include all the typical components of a feeding reaction induced by fish extract.

The conditioning of the tuna was discussed with respect to their response to fish extract. Obviously they had become conditioned to feeding on inert, dead rather than motile, living food for they had little interest in schools of small baitfish which at times were present in the pond in fair abundance and which would leisurely withdraw as the tuna approached. Obviously, also, they had become conditioned to being fed for they would mill close to an observer on his approach to the pond. It was concluded that the response of the tuna was not directly conditioned by the kind of food, i.e. the species of fish used as food. However, there was the possibility that the tuna formed an association between feeding and the smell or taste of the dead food, which was cut up or otherwise macerated and which might exude juices of similar composition. If so, the response would not necessarily be obtained from wild fish at sea.

Tester, Yuen and Takata[11] reported on further experiments with little tunny in the pond and with skipjack schools at sea. Pond experiments were improved by introducing test substances into a continuous stream of water which flowed directly into the attraction area at the foot of the observation tower. Continued screening of some 75 known compounds indicated a mere "sensing" of strong smelling materials. A carefully designed experiment involving feeding the fish at successive weekly intervals with cut-up squid, skipjack, and shrimp and testing their response to extracts of these same substances was conducted. A response to all three extracts was obtained regardless of the food being fed, but the response to a particular extract was slightly greater when the substance from which it was prepared was being used as food. This experiment tended to confirm the suspicion voiced earlier that the fish were conditioned to the smell of juices exuded from the food which presumably contained common or similar substances which stimulated the feeding response. It was hoped that, even so, tuna in their natural environment would respond to the extract, which might contain a substance exuded by living, injured, or uninjured prey to which "wild" fish were naturally conditioned. This hope was not realized.

Large quantities of extracts of skipjack, yellowfin, and anchovy were prepared during the winter, spring, and summer of 1953, tested on the captive little tunny and presented to schools of skipjack at sea. In a few instances the schools consisted mostly of skipjack but included yellowfin, little tunny, or frigate mackerel. In some tests the concentrated liquid extract was sprayed on the surface or pumped in a stream in the path of the schools. In others, it was presented to schools which had been *chummed** to the stern of the vessel by livebait (*Stolephorus purpureus*). The results were either negative or inconclusive. Unchummed schools could not be stopped by an arc or circle of extract. Chummed schools could not be held at the stern even when the extract was

Chum—live or chopped fish used as a lure.

bucketed overboard. In a few tests, on releasing a large quantity of the extract after the school had been chummed to the stern and chumming was stopped, a few fish were seen jumping in or passing through the material. It was uncertain whether they were responding to the extract or chasing stray baitfish. The apparently negative results discouraged any further testing of extracts except in conjunction with lures as reported below.

RESPONSE TO EDIBLE AND INEDIBLE LURES

Tester, Yuen, and Takata[11] describe pond tests with edible lures, and sea trials with both edible and inedible lures. The pond tests showed that little tunny would eat edible preparations such as gelatin capsules, pieces of macaroni, and strips of agar gelatin, and that these were more avidly consumed it they were made chemically attractive, or palatable, with concentrated extracts of skipjack or anchovy. In some cases, also, the feeding response seemed to be greater if the lures were made more visually attractive, i.e., silvery in colour. The fish showed a distinct preference for the agar preparations.

Again, the results of sea tests of edible lures were negative. However, they were conducted during the autumn when skipjack schools were scarce and erratic in their behaviour. Several of the schools which failed to respond to our most promising preparation (agar strips impregnated with concentrated extract and with aluminum powder) also failed to respond to livebait.

Several types of inedible lures were tested at sea. These were used as chum both alone and along with liquid extract after the fish had been initially chummed to the stern of the ship with baitfish. There was a momentary response to shiny objects such as strips of tin (several of which were eaten), to silvery objects such as squares of aluminum foil, and to effervescing objects such as calcium carbide pellets. Similarly there was a momentary response to dead baitfish. The addition of extract had no apparent effect. The results indicated that the sense of vision plays a much greater role in feeding than the sense of smell. However, neither the visual lures nor a "drag-lure array" (designed to simulate a school of baitfish) towed behind the vessel, was successful in holding the fish at the stern.

On the hypothesis that motion was an essential component in visual attraction, attempts were made (unpublished) to devise an expendable, self-propelled motile lure which would simulate baitfish movement, and which would be made both visually and chemically attractive. Many types of "motors" (mostly generating air or gas) were devised, but none was satisfactory. A compressed-air "machine gun" was designed to project and at the same time activate compressed air cartridges. Following an unsuccessful sea trial, hampered by imperfections in the machine and poor behaviour of the released cartridges, this idea was abandoned.

RESPONSE TO ELECTRICAL STIMULI

Before conducting experiments on the response of tuna to electrical stimuli, it was considered best to obtain pertinent basic data on a more readily available marine species which could be easily kept in captivity. During 1951, Tester[7] studied the response of aholehole (*Kuhlia sandvicensis*) to interrupted direct current using a D.C. generator and various types of mechanical interrupters In a small salt water tank ($12 \times 2 \times 1$ ft.) the fish were forced to swim to the positive electrode when subjected to suitable combinations of current and frequency of interruption. The results indicated that, at a frequency of 15 cycles a progressive saving of power could be obtained by reducing the "current-on" fraction of a cycle from about 0·7 to 0·1. Power conservation, of course, is an important consideration in the practicality of marine electrofishing.

The above results were confirmed and extended by Miyake and Steiger[5] in further experiments with aholehole during 1954 and 1955, using storage batteries as the source of power. They concluded that the optimum frequency for electrotaxis was 10 cycles and that the minimum peak current for satisfactory response (12 amp) was associated with an "on-fraction" of 0·06 to 0·08. Total peak current requirements decreased with increase in length of the fish extrapolating the above results, they concluded that a current of 130 amp. at a potential of 60 V. would be required to induce electrotaxis in a fish the size of a small tuna (30 cm.) using plane 11×4 ft. electrodes spaced a distance of 33 ft. This was best achieved by condenser discharge. Accordingly an apparatus was constructed for experiments with tuna and other large fish in the concrete tank. It consisted of a bank of capacitors (55,000 mfd.) charged by any number up to 10 pairs of automobile storage batteries arranged in series parallel. The charging and discharging of the capacitors was controlled by a variable speed mechanical contactor.

With electrodes spaced at 33 ft. perfect electrotaxic response was obtained with a jack (*Carynx sp.*), using 60 V. (2 banks of 10 batteries) at 10 cycles. However, with little tunny and yellowfin the results were either inconclusive or negative. By spacing the electrodes a distance of 16 ft., thus increasing the electric field, an excellent electrotaxic response was repeatedly obtained with yellowfin tuna (about 50 cm. in length). The results showed that power requirements decreased (10 to 6 pairs of batteries) as the frequency increased to 20 cycles, the limit of the apparatus. Theoretical calculations indicated that 23 times as much power would be dissipated in the open sea as in the closed tank and that a correspondingly higher power output would be required to effect electrotaxis with the same electrode spacing and frequencies

In the same report, Miyake and Steiger[5] presented theoretical studies of the potential, electric field, and current density for spherical electrodes submerged in a large body of water. They also investigated the theoretical relation ship between the head-to-tail potential and current density in a fish as determined by the relative conductivities of the fish and water.

Following the 1954-55 results, reported above, the possibilities of utilizing an amplidyne to generate a pulsed direct current of satisfactory strength, waveform, and frequency for inducing electrotaxis were investigated in the laboratory with promising results (unpublished). Unfortunately continuation of the contract work has not been possible because the contractors have assumed other responsibilities.

DISCUSSION

Despite the large amount of information which has been obtained on the response of both captive and wild tuna to stimuli of various kinds, little progress has been made toward attaining the main objective. This was to devise a method of catching surface tuna, which was independent of the use of livebait.

It was realised at the outset that our approach was largely "trial and error" and that the probability of success was small. It was also realized that results obtained on captive fish, conditioned to pond life, might not be capable of extrapolation to wild fish of the open sea. Nevertheless, the approach seemed worthwhile in providing leads which might be tested by sea trials.

The pond tests demonstrated that the active little tunny and the less active yellowfin both have a keen sense of smell (or taste), together with excellent vision both through water and, with a calm surface, through air. The sea tests indicated that the sense of smell plays little, if any, part in natural feeding, although this is still an open question (a) because of the difficulty in making observations on the response of fish at sea, and (b) because the materials tested may not have included those which might be associated with living prey. These studies might well be repeated or perhaps extended in view of our recent discovery of a natural laboratory, a spot or "concourse" in the lee of an island where skipjack are always present and where their behaviour and response may be readily observed by underwater viewing devices which are presently being perfected.

Sea tests further indicated that vision played an important, and perhaps a dominating part in natural feeding and that motility of a lure, whether living or dead, whether edible or inedible, was an important attribute. These observations, also, can be repeated and extended at the skipjack concourse.

Although most of our pond observations were made on little tunny and, to a lesser extent, on yellowfin, our sea tests were conducted mostly on schools of skipjack. This again leaves an element of uncertainty in drawing conclusions regarding the negative results of sea tests.

The response of tuna to auditory stimuli was not adequately investigated; this work was abandoned in favour of the more promising fields of chemical and electrical stimulation.

The possibility of electrofishing for surface tuna, either with or without the use of bait, remains a promising area of study. Now that it has been demonstrated that electrotaxis may be induced in tuna with an electric field of known characteristics, the problem is one of engineering rather than biology.

Future efforts to devise new or improved methods of tuna fishing will be enhanced by further studies of the behaviour of tuna and their response to factors of the environment. Behaviour studies are rapidly becoming one of the major areas of research of the Pacific Oceanic Fishery Investigations and will occupy more and more of our attention in the years to come.

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Tuna Season in the Marquesas

By
ROBERT C. WILSON
and
THOMAS S. AUSTIN

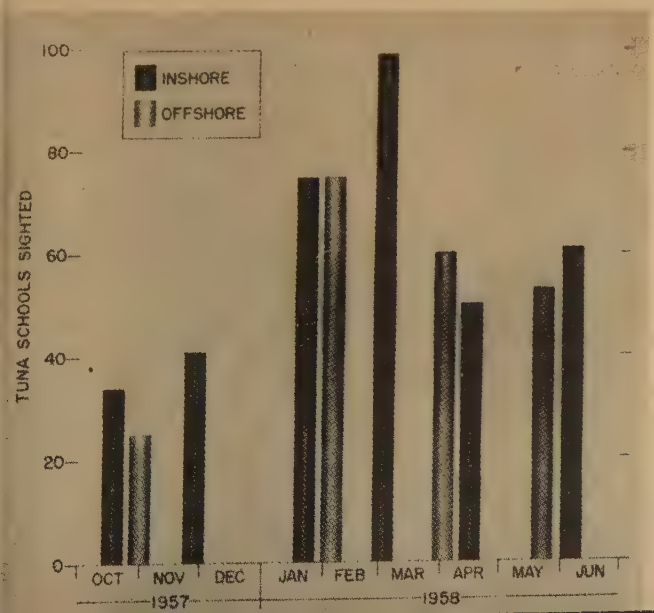
". . . The Marquesas! What strange visions of outlandish things does the very name spirit up! . . . As we draw near the land, I hailed with delight the appearance of innumerable sea fowl."

Herman Melville, "Typee."

● Many travelers have noted the myriads of sea birds about the Marquesas Islands, but it was not until the development of the tuna fisheries elsewhere that their possible economic significance was realized. Both the bird flocks and the schools of tuna have the same prey—the groups of small fish which provide their main food. More often than not, it is these flocks of birds which guide tuna fishermen to the schools.

Since mid-1956 the Pacific Oceanic Fishery Investigations (POFI) of the U. S. Fish and Wildlife Service has been engaged in a program, the primary purpose of which has been to describe the abundance of tuna schools in northeastern French Oceania, and more particularly the Marqueasas Islands. Most of the effort in this program has been focused on the Marquesas, because the group can be easily reached by the long-range segment of the American tuna clipper fleet, and the Marquesan sardine is available there as a possible supplementary supply of live bait.

The Marquesas Islands lie approximately 2,850 miles from San Diego. The group is governed by the French. They are high islands, and suitable areas for anchorage in the bays are numerous. The group lies in the belt of southeasterly trades, which are generally moderate, affording very few days when fishing cannot be carried on. Diesel fuel is not available there, but our vessels have obtained water at Taiohae, Nuku Hiva. Fresh fruit may be purchased from the Marquesans who are a Polynesian people.



Marquesan Survey results of the tuna schools scouting by POFI operations on inshore and offshore waters of the Marquesas, 2,850 miles from San Diego.

● Preliminary surveys of the area were conducted during August-September, 1956, (Marquesan winter) and January-March, 1957 (Marquesan summer). These cruises involved study of the oceanography of a broad area about the Marquesans, longline fishing for deep-swimming tunas, and surveys of the surface tuna schools in the Marquesas and Tuamotus. Results of these preliminary surveys revealed a striking difference in the abundance of tuna schools. They were about three times more abundant during the summer period (January - March, 1957) than during the winter period (August-September, 1956). Results also showed a higher concentration [illegible] organic phosphate and zoopl[illegible] indices of the primary produ[illegible] the area, during the winter.

In October, 1957, the surveys took a more definite turn, with the beginning of studies designed to determine the length of the season of greatest abundance of surface tuna schools in the Marquesas group and, to a limited extent, in the Tuamotu archipelago.

● There were two standardized types of surveys conducted, the "inshore" and the "offshore", which followed the tracks shown on Page 31. All of the

tracks were run during daylight hours, and tuna "schools" were defined according to the following criteria:

1. Tuna school seen breaking the surface, birds may or may not be present.
2. A "working" (diving and feeding) flock of 50 or more birds seen, tuna breaking the surface may or may not be present.

Results from the inshore surveys conducted during October 1957-June 1958 (fig. 5) confirmed the greater abundance of surface tuna schools during the summer months, as follows:

Dates	Number of schools sighted
October 14-21, 1957	34
November 24-30, 1957	41
January 18-25, 1958	75
Feb. 27-March 5, 1958	99
April 11-19, 1958	50
June 1-10, 1958	61

In addition, four standardized offshore surveys were conducted, which further confirmed the seasonal nature of tuna distribution in the area:

Dates	Number of schools sighted
Oct. 24-Nov. 6, 1957	25
Jan. 28-Feb. 11, 1958	75
March 26-April 8, 1958	60
May 15-29, 1958	53

From these data it appears that within the period of the surveys, the abundance of tuna schools in the Marquesas area reached a peak during January-March, gradually tapering off thereafter.

About 80% of the identified schools kipjack, 15% were Yellowfin, remaining 5% were mixed and Yellowfin. Virtually all small Yellowfin taken were from mixed schools. Of the schools of large 2- and 3-pole Yellowfin chummed, we were never successful in getting them to bite in any significant number. All of the Skipjack taken during the inshore surveys were under 10 pounds in weight, with most in the 4-6 pound weight group. However, Skipjack in the 18-22 pound weight class comprised 32% of the samples taken during the offshore surveys, with the remainder of a smaller size.

● The fishing success of POFI's research vessels is not necessarily comparable to that of a large tuna clipper because of restricted amounts of bait, fewer men in the racks, and the necessity to catch fish at a slow rate for tagging. The behavior of the schools can, in general, be described as wild and fast traveling.

The results of surveys of limited duration conducted in the northwest portion of the Tuamotu archipelago are perhaps more encouraging than those from the Marquesas. While the rate of sighting schools was lower, the schools were less wild, the fish bit better, and large Skipjack were relatively more numerous in the catch.

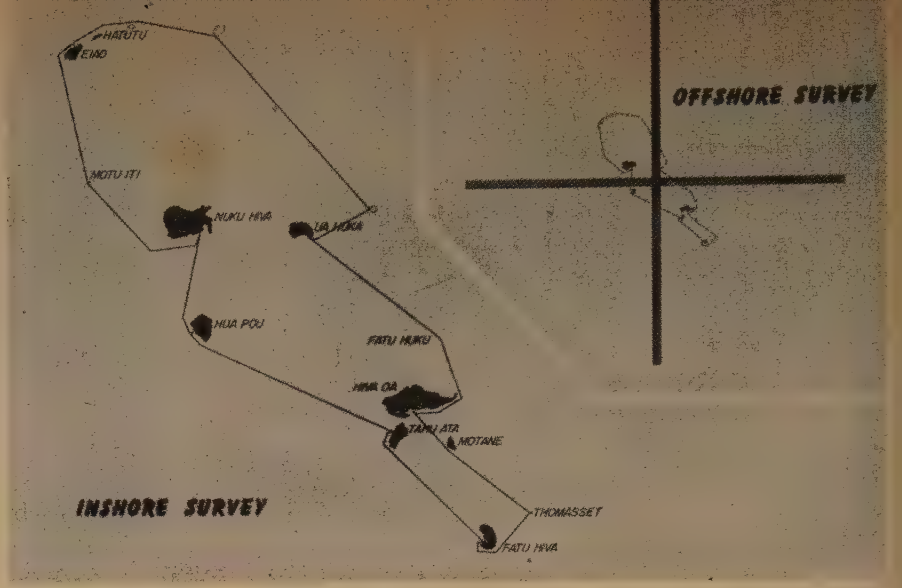
In the Marquesas and Tuamotus, 4,584 Skipjack and 196 Yellowfin have been tagged and released, using the new POFI D-2 dart tag. To our knowledge, not one of these tagged fish has been recaptured. This is in striking contrast with the 9.7% recapture of Skipjack marked with the same type tag in the Hawaiian area. Thus it appears that the absence of returns from Marquesan fish is due to lack of fishing, and that this stock is presently unexploited to any great extent.

● The bait used during the fishing surveys was the Marquesan sardine. These fish, when used as chum, remain near the surface, form small schools, and attract and hold the tuna schools near the vessel. They do not withstand extreme crowding, either during transport to the vessel, or in the wells aboard. Once adjusted to life in the baitwells, they survive well. Most of the sardines were taken in shallow water of the bays, over sandy bottom.

But the supply of sardines has proven unreliable. During bait surveys made in January 1957, 1,200 scoops of bait were seen in Taiohae Bay, Nuku Hiva, and 500 scoops in Anaho Bay, Nuku Hiva. However, during the period January-June 1958, our vessels had great difficulty in scratching up the small quantities (100-200 scoops) of bait needed for survey work. So we cannot state with any certainty that a tuna clipper might procure sufficient supplementary bait in the area.

Examinations of the stomachs revealed a much higher percentage of fish in their diet than was the case in Hawaiian waters. Most of the fish species in the Marquesan Skipjack stomachs were those commonly thought to be associated with the proximity of land as has also proved true in Hawaii.

The conduct of POFI descriptive and exploratory programs has in general followed three phases: First an evaluation of the area and its environment, second a study of the fishery resource, and finally, an evaluation of the commercial possibilities. The first two phases are now completed. Currently under study are plans for evaluation of the commercial possibilities by encouraging a tuna clipper to conduct full-scale commercial fishing operations in the area during the January-March 1959



Where they Searched for tuna in the waters about the Marquesan Archipelago 8° degrees below the Equator on the 140th meridian.

Oceanic Skipjack tagged with the new type of dart tag finding favor with biologists as the best means of marking tuna yet devised.

DISPLAY COPY

Tagging of Skipjack in Hawaiian Waters

DANIEL T. YAMASHITA and KENNETH D. WALDRON[1]

Reprinted from PACIFIC SCIENCE
October, 1959

Tagging of Skipjack in Hawaiian Waters

Daniel T. Yamashita and Kenneth D. Waldron[1]

The fishing of the Hawaiian skipjack (*Katsuwonus pelamis*) though relatively small if compared with the major fisheries of the United States, is the most important commercial fishery in the Hawaiian Islands and the only American fishery exploiting mid-ocean stocks of skipjack. Annual landings average about 11,000,000 pounds with a value to the fishermen of about one and a half million dollars.

The Pacific Oceanic Fishery Investigations (POFI), of the U. S. Fish and Wildlife Service, is engaged in a skipjack tagging program which, it is hoped, will provide information that will increase the effectiveness of the local fishery. Tagging offers a direct means of increasing our knowledge of the growth rates, general migrations, and inter-island movement of the fish. In this report we will describe the type of tags used and the results of our initial studies during the years 1954 to 1956.

A major difficulty in early tuna tagging investigations (Rounsefell and Kask, 1945; Wilson, 1953) was the lack of a suitable tag. Alverson and Chenoweth (1951) contributed to the development of a better tag by their water tunnel experiment to determine the effect of flowing water on various tags attached to frozen albacore (*Germo alalunga*). Following this work, the California Department of Fish and Game developed a tubular plastic tag (Wilson, 1953) and used it extensively for tagging albacore, yellowfin (*Neothunnus macropterus*), and skipjack tuna (Ganssle and Clemens, 1953; Blunt, 1954); this tag is often called the type G or spaghetti tag.

Prior to announcement of the successful California tag, POFI experimented with several other types, both at sea and in ponds. These tests involved internal tags and external tags of the hook and streamer type. Experiments conducted in 1950 and 1952 were either inconclusive or unpromising, so the California tag (Fig. 1) was adopted for use in Hawaiian waters from 1954 to 1956.

Application of the Tags

The type G tag was applied in the manner described by Wilson (1953), with certain modifications. Skipjack were caught by live-bait fishing methods as described by June (1951), with 3 or 4 men in the racks. A skipjack was hooked, swung up, caught by the fisherman, passed to a man designated as "holder," the tag was attached, and the fish was returned to the water. With an experienced crew a skipjack could be tagged and returned to the water in about 20 seconds.

Because it is difficult to handle skipjack without injuring them, various methods including canvas cradles, padded boxes, and electronarcosis were used in attempts to calm the fish. None of these was successful. Since it was deemed necessary to return skipjack to the water as rapidly as possible and since our efforts to quiet the fish were unsuccessful, no attempt was made to measure individual fish. Instead an estimate of the size of skipjack tagged was obtained by measuring fish which were caught and not tagged. Brock (1954) has shown that skipjack school by size, so it was believed that a reliable estimate of the size of tagged fish was obtained in this manner.

[1] Fishery Research Biologists, Pacific Oceanic Fishery Investigations, Honolulu, Hawaii. Manuscript received March 12, 1958.

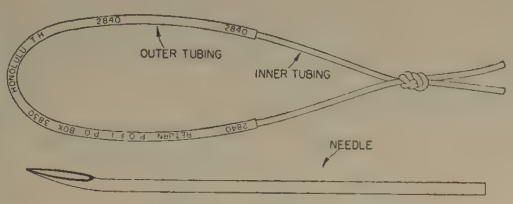


FIG. 1. California type G tag and tagging needle. Legend is on inner tubing only; serial numbers on inner and outer tubing.

Most of the skipjack tagged as described above sounded immediately upon release. On a few occasions they were seen to lead fish from the accompanying school away from the stern of the vessel. While some tagged fish left the school when released, there were indications that others remained in the same school from which they were caught. In one instance a fish released with a white type G tag was observed accompanying the vessel with part of the school for 4½ hours.

RELEASES

Between May, 1954, and July, 1956, 1,961 skipjack were tagged with the California type G tag and released in Hawaiian waters (Fig. 2).[2]

Most of the releases were within the area of the Hawaiian skipjack fishery; a few were released outside this area. This release pattern was followed in order to (1) establish the rate of recovery within the fishery, (2) study the movements of skipjack within the fishery, and (3) ascertain the direction from which skipjack approach Hawaiian waters.

It should be pointed out that the tagged fish were smaller than the usual size (18–22 pounds) composing the season's commercial landings. Eighty-five per cent were 10 pounds or smaller, 14 per cent between 11 and 20 pounds, and only 1 per cent larger than 21 pounds. The small percentage of releases in the larger size categories is due partly to the difficulty in handling these fish, and partly to the general scarcity of large fish when most of our tagging was done.

[2] In addition, 20 skipjack were tagged with white type G tags and released in the vicinity of the Line Islands, and 12 with blue type G tags northeast of Midway Island.

PUBLICITY PROGRAM

Publicity is an important part of most tagging programs, because one way to maximize the returns is to minimize the loss of tags recovered but not noticed by persons unaware of the program. We conducted personal interviews with skipjack fishermen on all islands and distributed posters to major fishing companies, fishing supply centers, and ports throughout the Hawaiian Islands. Fishermen were also informed of our tagging activities through radio broadcasts, transmitted by POFI vessels during their cruises in Hawaiian waters, and through informal letters. Also, wardens of the Hawaiian Division of Fish and Game stationed on the various islands were furnished photographs of tagged skipjack, together with standard recovery information forms. Because of the distinctive appearance of the tag, the publicity program, and the extensive handling of individual fish (when caught, during stowage and unloading of catch, and during butchering at the cannery), the possibility of loss of tags through nonrecognition of tagged fish was considered negligible.

Rewards for the return of tags were not part of the recovery program. Instead we purchased the tagged fish at a price slightly above the market value. A letter giving pertinent information was also sent to the person, or persons, involved in the recovery.

RECOVERIES

Of the 1,961 skipjack tagged and released, 9 were recovered by the commercial pole-and-line fishery and 3 from the stomachs of large longline-caught tunas between July, 1955, and February, 1956. The areas of release and recapture for these 12 skipjack are shown in Figure 3 and listed in Table 1. The low rate of recovery, 0.6 per cent, may be attributed in

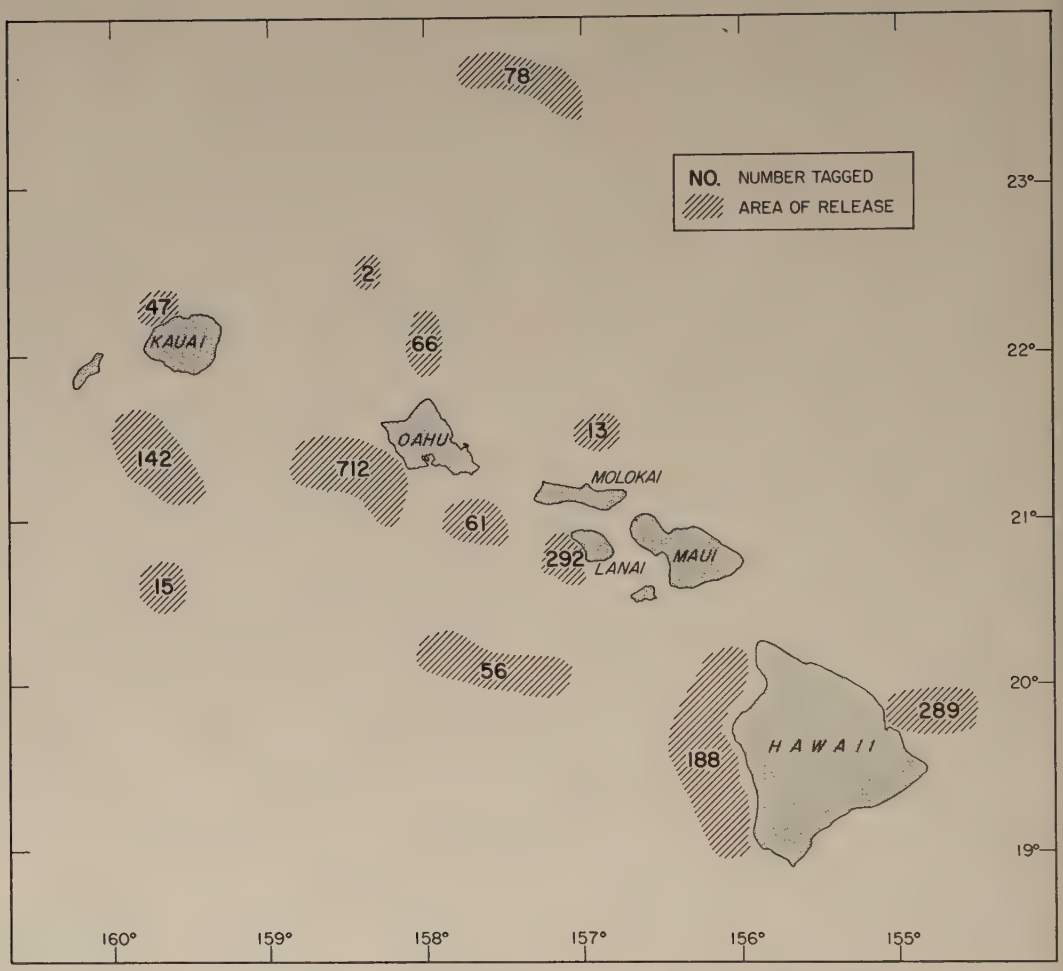


FIG. 2. Skipjack releases in Hawaiian waters, May 1954–July 1956.

part to a combination of the following factors: (1) the initial tagging mortality resulting from handling in the tagging process may have been high; (2) mortality caused by predation of large tunas and spearfishes may have been excessive; and (3) certain groups of tagged skipjack may have moved out of the area covered by the fishery.

Condition of Tags and Fish: The condition of the tag and of the skipjack was noted for each of the 9 pole-and-line caught recoveries. One fish, recaptured after only 6 days at liberty, showed quick recuperation. The tag wound appeared raw and enlarged but there were no signs of infection. Another skipjack, retaken 12 days after tagging, had new skin forming around the edges of the tag wound.

Most of the recovered fish showed a slight chafing of the anterodorsal margin of the caudal fin, caused by the free ends of the tag striking the fin. This could be prevented by trimming the ends of the tag after the knot was tied.

One skipjack recaptured 252 days after release bore only the outer jacket portion of the tag. This protruded from the right side of the fish. The wound on the left side had

TABLE 1
POFI SKIPJACK RECOVERIES WITH WHITE CALIFORNIA TYPE G TAG

ORDER OF RECOVERY	WEIGHT RANGE OF SCHOOL AT RELEASE	DATE TAGGED	DATE RECOVERED	DAYS OUT	DISTANCE TRAVELED	WEIGHT AT RECOVERY	REMARKS
	Lbs.				Miles	Lbs.	
1	5–10	6/1/55	7/12/55	41	0	3–4	Recaptured from one school
2	6–8	6/8/55	7/12/55	34	0	3–4	
3	3–5	7/20/55	7/26/55	6	40	4	
4	5–8	7/18/55	7/30/55	12	0	6	
5	3–6	8/22/55	8/24/55	2	6	3½	Found in stomach of longline-caught 189-lb. yellowfin
6	3–5	7/20/55	8/28/55	39	17	4	
7	4	8/17/55	8/17–8/26/55	0–9	0(?)	–	Tag only found in stomach of longline-caught 190-lb. yellowfin
8	3–5	8/25/55	8/25–9/1/55	0–7	0	4	Found in stomach of longline-caught 209-lb. bigeye
9	4–5	8/8/55	8/29/55	21	14	3	Recaptured from same school
10	4–5	8/8/55	8/29/55	21	14	3	
11	4–5	8/8/55	10/29/55	82	9	4½	
12	5½–9½	5/25/55	2/1/56	252	30	14	

healed completely and was marked only by a black spot on the skin (Fig. 4). Adhesion between the flesh and the plastic held the tag in place.

Movement: All of the skipjack recovered were small (3 to 10 lbs.) when tagged. They showed surprisingly little movement, all of them being recaptured within 40 miles of the point of release (Fig. 3 and Table 1). There was no inter-island movement of tagged fish. The probability of recovery of tagged skipjack in offshore waters (beyond 50 miles from land) is low because very little fishing is done in this area. However, each of the main Hawaiian islands has fisheries within 20 miles of shore, so this lack of evidence of inter-island movement cannot be attributed to the distribution of fishing effort.

Two of 39 fish (Table 1, recoveries 9 and 10) released in one group were recaptured 3 weeks later from a single school, indicating that a school of skipjack retains its identity as a unit for some time. Recoveries 3 and 6 tagged on the same day and from the same school, may provide an example of the usefulness of this hypothesis. This school may have traveled 63 miles between July 20 and August 28, 1955; 40 miles to where No. 3 was retaken, and 23 miles back to where No. 6 was retaken. Similarly, the group in which recoveries 9, 10, and 11 were released may have traveled a minimum of 37 miles between August 8 and October 29, 1955. These are straight-line distances, and in all likelihood a much greater distance was covered during this period.

Growth: Information concerning the rate of growth of skipjack was gained from a tagged fish which weighed 14 pounds when recovered after 252 days (8.4 months) at liberty. Based on the average weight of fish (7 pounds) and the size range of fish (5.5 to 9.5 pounds) in the school at the time of release, a comparison may be made with the growth rates obtained by Brock (1954) in his length frequency studies. If this tagged fish was at the lower end of the size range (i.e., 5.5 pounds) when tagged, it grew at the rate of about 1.0 pound per month. This closely approximates Brock's estimate of 1.2 pounds

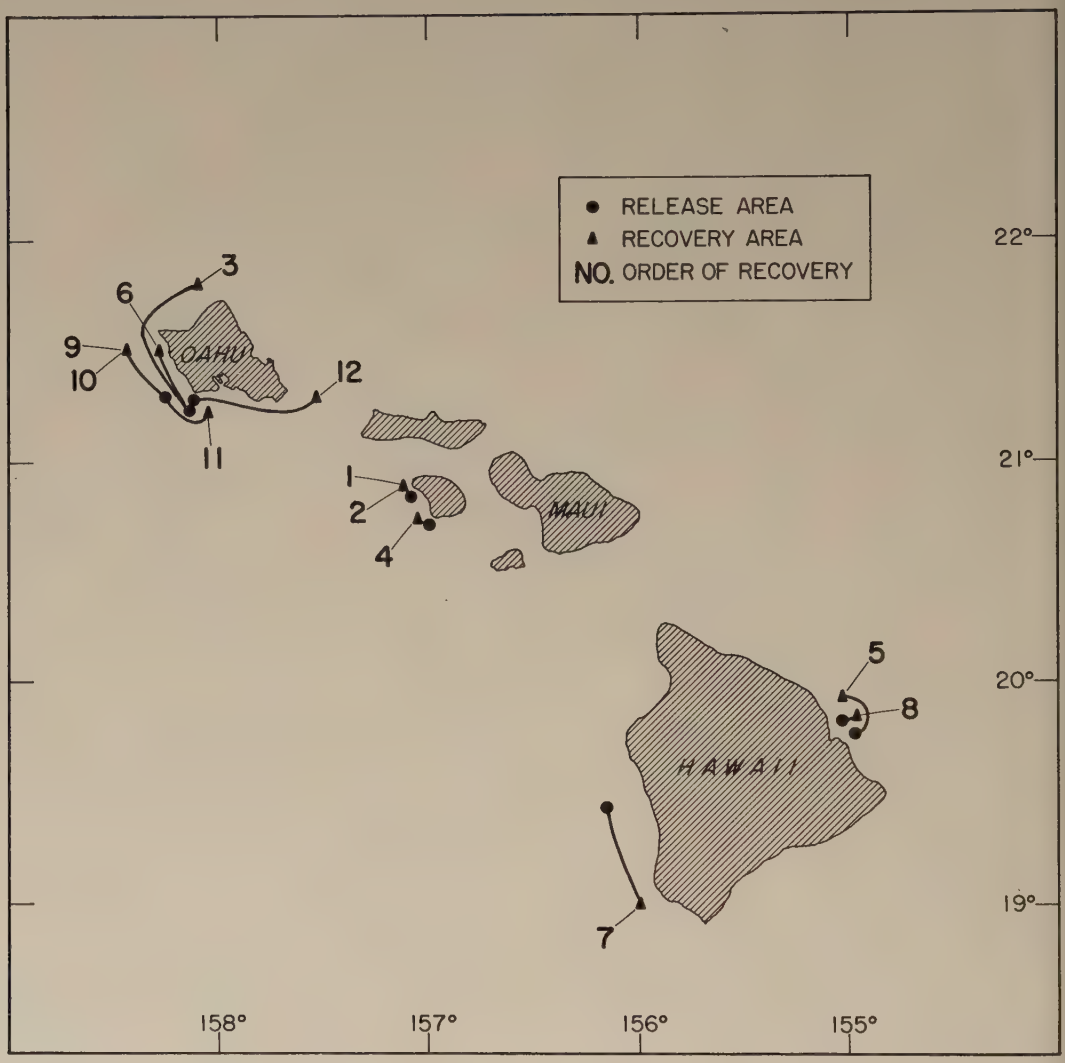


FIG. 3. Skipjack recoveries in Hawaiian waters, July 1955–February 1956.

per month for skipjack of this size (from his fig. 2). If the fish was of average size (i.e., 7 pounds) at the time of release, then a growth of 0.8 pound per month is indicated, which is slightly more than one-half the growth of 1.4 pounds per month shown by Brock. Finally, if the fish was at the upper limit of the size range (i.e., 9.5 pounds), it grew at the rate of 0.5 pound per month, or one-third the rate of growth of 1.5 pounds per month indicated by Brock.

Predation: There was evidence that some loss of tagged skipjack resulted from predation. Two tagged skipjack and one tag were recovered through incidental examination of stomachs of large tuna caught by longline near the island of Hawaii (recoveries 5, 7, 8 in Table 1). All three skipjack weighed about 4 pounds and were recovered within a few days of release. They were the only recoveries of skipjack released in that area.

In order to determine the incidence of skipjack, tagged or untagged, in the stomachs of larger fish, a sampling program at the

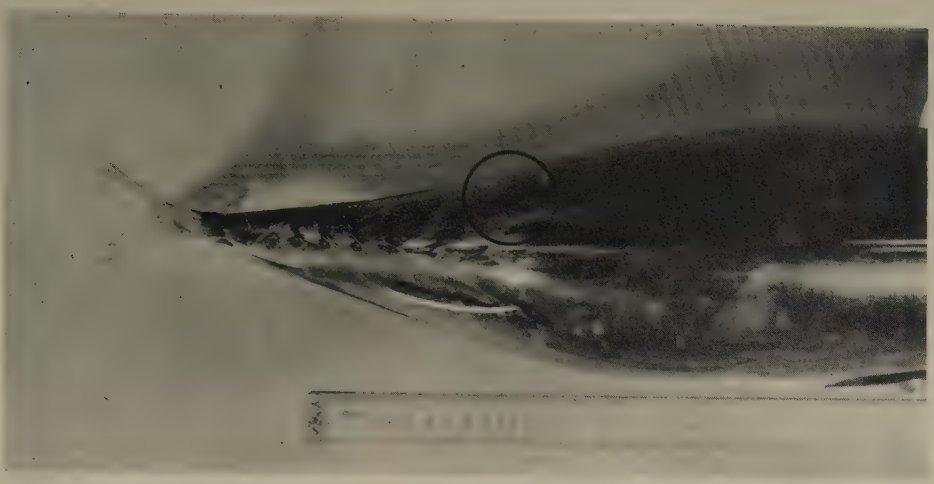


FIG. 4. Tagged skipjack recovered 252 days after release with only the jacket portion of the tag still in place. Dorsal view showing healed wound (dark area in circle) on the left side. Photograph by E. D. Stroup.

Honolulu auction markets was carried out between October, 1955, and June, 1956. During this interval, which included periods when skipjack were being tagged and released within the fishery, stomachs were examined from 538 bigeye (*Parathunnus sibi*), 103 yellowfin, 128 striped marlin (*Makaira audax*), and 74 black marlin (*Makaira ampla*) taken in the Hawaiian longline fishery. Twenty-eight of these stomachs (3.3 per cent) contained a total of 30 skipjack, none of which was tagged. Furthermore, only 9 of the 30 skipjack were as large as those being tagged, i.e., 2 pounds or larger, and the rest were estimated to be 1 pound or less. Only one large skipjack was taken from the stomach of a tuna; the others were from black and striped marlins. Unfortunately, there are no comparable data concerning the number of untagged skipjack from stomachs at the time the three tagged fish were found, but on the basis of subsequent sampling it seems that there was a higher rate of predation on tagged than on untagged fish.

SUMMARY

A tagging project was inaugurated to study migrations and to supplement our knowledge of growth of skipjack in Hawaiian waters.

During the period 1954–1956, California type G tags were attached to 1,961 skipjack released in Hawaiian waters. The majority of these fish weighed less than 10 pounds.

Only 12 or 0.6 percent of these fish were later recovered. This low recovery rate may be attributed to tagging mortality, predation, and movement out of the fishery.

The longest interval between release and recovery, by pole-and-line fishing, was 252 days and the shortest interval was 6 days.

Net movement was limited to 40 miles or less and no inter-island travel was shown.

The tag wounds on recovered skipjack were enlarged but well healed after 12 days. When used on smaller fish, the free ends of the tag caused chafing of the anterodorsal margin of the caudal fin.

One skipjack weighing 14 pounds at recovery grew at an estimated rate of 0.8 pound per month over an 8½-month period.

Predation by large tunas and spearfishes may be greater on tagged than on untagged skipjack. This conclusion is based on the recovery of three tagged skipjack from the stomachs of large tuna.

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VARIABILITY OF SKIPJACK RESPONSE TO LIVE BAIT

BY HEENY S. H. YUEN

FISHERY BULLETIN 162
From Fishery Bulletin of the Fish and Wildlife Service
VOLUME 60

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
BUREAU OF COMMERCIAL FISHERIES

UNITED STATES DEPARTMENT OF THE INTERIOR, Fred A. Seaton, *Secretary*

FISH AND WILDLIFE SERVICE, Arnie J. Suomela, *Commissioner*

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VOLUME 60

PUBLISHED BY U.S. FISH AND WILDLIFE SERVICE • WASHINGTON • 1959

PRINTED AT THE U.S. GOVERNMENT PRINTING OFFICE, WASHINGTON

For sale by the Superintendent of Documents, U.S. Government Printing Office,
Washington 25, D.C. Price 20 cents

Library of Congress catalog card for the series, Fishery Bulletin of the Fish and Wildlife Service:

U. S. *Fish and Wildlife Service.*
Fishery bulletin. v. 1–
Washington, U. S. Govt. Print. Off., 1881–19

v. in illus., maps (part fold.) 23–28 cm.

Some vols. issued in the congressional series as Senate or House documents.
Bulletins composing v. 47– also numbered 1–
Title varies: v. 1–49, Bulletin.
Vols. 1–49 issued by Bureau of Fisheries (called Fish Commission, v. 1–23)

1. Fisheries—U. S. 2. Fish-culture—U. S. I. Title.

SH11.A25 639.206173 9—35239*

Library of Congress [59r55b1]

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ABSTRACT

Observations made from commercial skipjack live-bait fishing boats, operating from Honolulu, revealed that catch rates for each school of skipjack had a general pattern: the rates rose to a peak and then declined with elapsed fishing time. In this paper, peak catch rate and duration of fishing after the peak were selected as measures of biting response and were compared with data on location, the weather, time of day, and stomach contents. With a fork length of 60 cm. as the dividing line between small and large skipjack, the peak catch rates for small fish were higher than those for large fish, but this was attributed to the greater ease of catching small fish. The peak catch rate of large skipjack increased with the distance from land. The postpeak duration of fishing for large skipjack was found to be negatively correlated with volume of stomach contents and relative time since the last major feeding. Large skipjack feeding on fast-swimming fish seemed to show a better response to chum (live bait) than did those feeding on slow-swimming fish. Weather conditions did not seem to affect the peak catch rate or the postpeak duration. The relation of biting response to time of day was not obvious.

VARIABILITY OF SKIPJACK RESPONSE TO LIVE BAIT

By Heeny S. H. Yuen, *Fishery Research Biologist*, BUREAU OF COMMERCIAL FISHERIES

Fishermen in the Hawaiian Islands chum live bait to attract skipjack (*Katsuwonus pelamis*) to the ship and to hold them there. The reaction of skipjack to chumming may vary from no response to feverish feeding activity which results in a sizable catch. In reporting the results of live-bait fishing aboard research ships of the Pacific Oceanic Fishery Investigations [1] in Hawaiian waters, Royce and Otsu (1955) stated that fish were caught from only 43 percent of the schools chummed. Time and bait expended on nonresponding schools represent a considerable economic loss to the fishermen, particularly because of the short supply of bait.

If the efficiency of the fisherman is to be improved, the factors which contribute to the variability of skipjack responses to chum should be ascertained. A prerequisite to this would be to measure the extent of variability of biting behavior. It is the intent of this study to measure and determine the reasons for the variability of skipjack response to chum.

Perhaps the measure of variability of response will have further application. For instance, it may be used to evaluate the success of new bait species and artificial baits, or to compare the response of skipjack in unexploited areas to that of present commercially successful areas.

Factors influencing the biting behavior of skipjack, as presented by past studies, may be classified as environmental, physiological, and psychological or perhaps psychophysiological. Among the environmental factors in the Japanese skipjack fishery, Imamura (1949) mentioned water clarity, current velocity, weather, abundance of natural food, and time of day. Transparency, chlorinity, and temperature of the water are advanced by Uda (1940b) as affecting skipjack catches, but probably as migrational rather than response determinants. Uda (1940a) and Suyehiro (1938) also mentioned time of day as a factor. The latter also noted the effect of seasons and the proximity of land on biting behavior.

The first physiological factor that comes to mind when considering biting response is the state of hunger. Both Uda (1933) and Suyehiro (1938) investigated its effect; the former in terms of fullness of the stomach and the latter in terms of time since last feeding. That the state of gonad development may also be a factor is indicated by Brock (1954) who reported a dearth of ripe individuals despite extensive sampling of the Hawaiian skipjack fishery.

The factor that was considered as a psychological or psychophysiological one was the possible preference of the skipjack for certain species of prey or perhaps for prey with certain types of behavior. This possibility was conjectured because of Suyehiro's (1938) statement that skipjack feeding on pelagic forms responded to chum better than those feeding on inshore forms. The effect of school size, if any, would also fall in this category.

The size of the skipjack and the fishing effort measured by the number of hooks fished were also considered as possible factors.

Since the data were collected by investigators who were permitted aboard commercial vessels with the provision that they would not interfere with the fishing operations, not all of the possible factors mentioned could be measured. Unfortunately, the data not collected fell in the environmental category.

Operations on a skipjack sampan are not geared to accommodate observers, but the following captains and crews went out of their way to make us comfortable and to help us collect our materials: Yoshiichi Teramae and crew of the M/V *Neptune*, Tsuruichi Sarae and crew of the M/V *Orion* (1956), Richard Kinney and crew of the M/V *Orion* (1957), Noboru Tsue and crew of the M/V *Buccaneer*, Tom Fukunaga and crew of the M/V *Angel*, and Kuniyoshi Asari and crew of the M/V *Marlin*.

NOTE.—Approved for publication September 26, 1958.

[1] Redesignated Bureau of Fisheries Biological Laboratory, Honolulu, effective January 1, 1959.

METHODS

COLLECTION OF DATA

Data were collected by observers who accompanied skipjack sampans throughout the 1956 and 1957 skipjack seasons, April through September, at about weekly intervals. Only the more successful and larger of the sampans were chosen because the probabilities of getting data would be enhanced and the larger deck permitted collection of materials with less interference to fishing operations.

A review of fishing operations described in greater detail by June (1951) follows: the boat leaves port early enough to be at a promising fishing area at daybreak. It is usually held on an arbitrary course while the scouts scan the ocean for birds that flock over fish schools. When a flock is sighted, the boat is steered to head it off. On reaching the head of the flock, the boat is slowed, water sprays are turned on, and chumming is started. The bait is dribbled out as evenly as possible until signs of surfacing fish are seen astern. When the fish begin to surface, the chummer intensifies the chumming until the fish are directly at the stern within reach of the hooks, at which time he reduces the rate of chumming to what he considers a minimum to keep the school at the boat. If the school moves away without responding, chumming is stopped and the boat accelerated to get into position for another attempt. As soon as the school has been successfully lured to the boat, the fishermen get into position at the stern and start fishing. The school is fished until the bait supply is exhausted or until the captain decides that the rate of catching is too slow to be worth while. The catch is stored as soon as fishing is stopped, and the boat then proceeds homeward or to look for more schools depending on the bait supply and hour of day.

The fishing of 92 skipjack schools was observed. Recording of data started with the sighting of a flock. The time of sighting was recorded to the nearest minute. During the approach a description of the weather was recorded. It included the height of the waves, an estimate of wind velocity and direction, the type of clouds and amount of sky covered, and light conditions. "Light" was described as bright sun, cloudy-bright, hazy, dull, and raining.

A running description of the activity of the flock was kept during the approach, and when the boat was close enough an estimate was made of the number in each flock and the species. The flocks were described as flying high, diving, scattering, regrouping, enlarging, etc. In the beginning, attempts were made to estimate the direction and velocity of the flocks but these were abandoned as being unreliable. As soon as contact with the school was made, its location was approximated.

The times of the following events were recorded to the nearest 5 seconds: (1) the beginning and end of each pass, (2) the first signs of fish surfacing in response to the chum, (3) the start of fishing, and (4) the landing of the first fish. During the few instances when the slowing of the boat and the start of chumming did not coincide, the latter was considered to be the start of the pass. The placement of hooks in the water signified the start of fishing.

As fish were caught, each was tallied on a counter. At the end of each minute (when the second hand pointed to 12) the reading was recorded with the time. If fishing did not start exactly on a minute, an error with a limit of plus or minus 30 seconds was introduced in the first minute. On earlier trips the catch was recorded at 2-minute intervals. Occasionally an individual fisherman left his post to change his fishing pole or to perform other duties such as helping the chummer, or to gaff fish. Each change in the number of men fishing and the time was noted, except when a man went to change his pole, a temporary absence.

The possibilities for error, especially when the fish were landed rapidly, were ever present with the observer watching the time, tallying the number of fish caught, accounting for the movements of the fishermen, and recording. Another method which decreased the amount of work during the hectic time of fishing and thereby reduced the possibilities of error was later used. This included the use of a movie camera with a single-frame trigger and a marine clock with white numerals against a black background. These were mounted facing each other (fig. 1). The shutter was released as each fish was caught, resulting in an exact record of the time of capture. The number of frames used corresponded to the number of fish

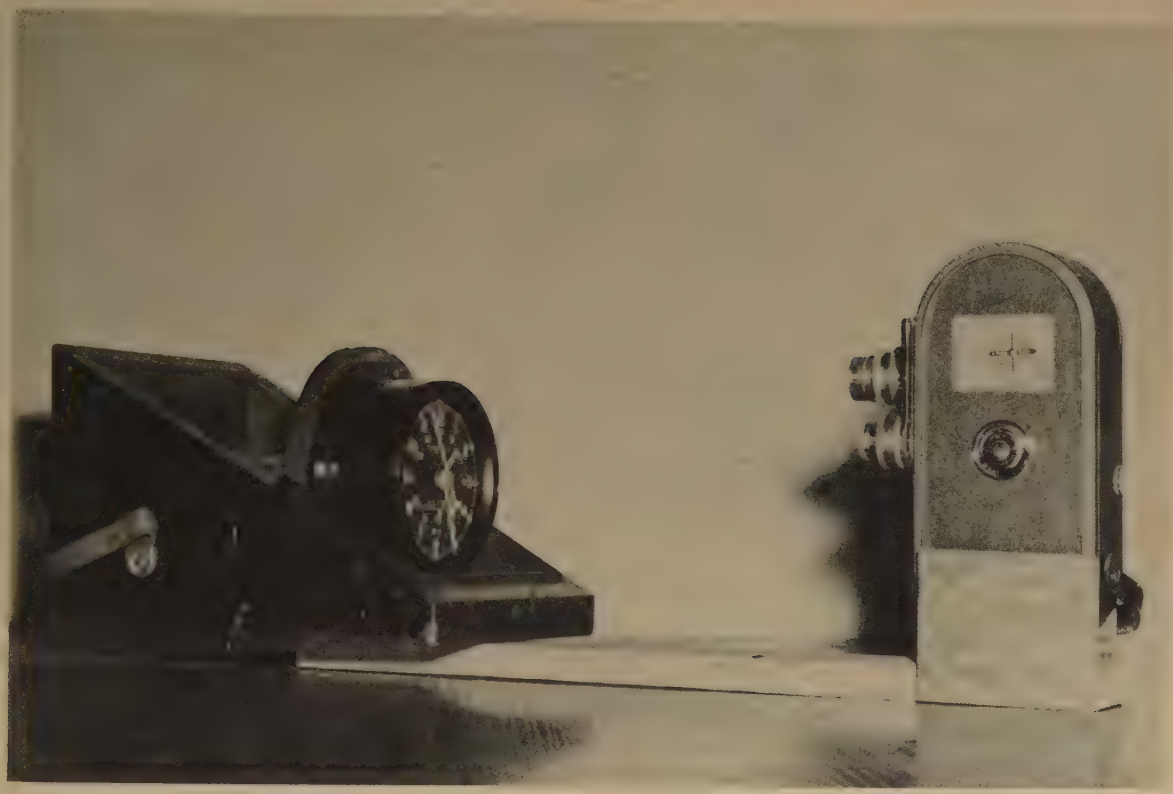


FIGURE 1.—Photograph of clock and camera setup.

aught. An additional hand on the clock was anipulated to point to the numeral correspond-ng to the number of men fishing at any time.

The precision of this system depended on the peed at which the single-frame trigger could be perated. The smallest possible interval of time etween frames was 0.6 second. This means that hen several fish were caught simultaneously, the ecord would indicate that they were caught 0.6 econd apart.

At the cessation of fishing, the skipjack were ndomly sampled. At first the sample size was), but this was later reduced to 10. The sample mprised the entire catch when the catch was less an the prescribed sample size.

The fork length of each fish in the sample was ken, then the stomach and a piece of the gonads ere removed and placed in a muslin bag. The omach was punctured while in the bag and the g secured and placed in approximately 10-per-nt formalin. Five hundred and thirteen fish, presenting 43 schools, were treated in this anner.

During the period between the 1956 and 1957 seasons, the personnel of the M/V *Buccaneer* collected 60 stomach samples from 6 schools. The data collected with the samples included: (1) the location of the school, (2) the time of fishing, (3) an estimate of the weight of the total catch from the school, (4) an estimate of the average weight of the fish, and (5) a statement of whether fish response was good, fair, or poor.

TREATMENT OF DATA

The rate at which the fish were caught, in terms of fish per hook-minute, was calculated for each minute of elapsed fishing time for the schools observed later in the study. For the schools observed earlier, the nature of the data did not permit the rates to be calculated for intervals of less than 2 minutes.

In the identification of the stomach contents the fish were placed in their families, mollusks in their suborders, and crustaceans in their orders. The individuals in each category were counted. The volume for each category was ascertained by water

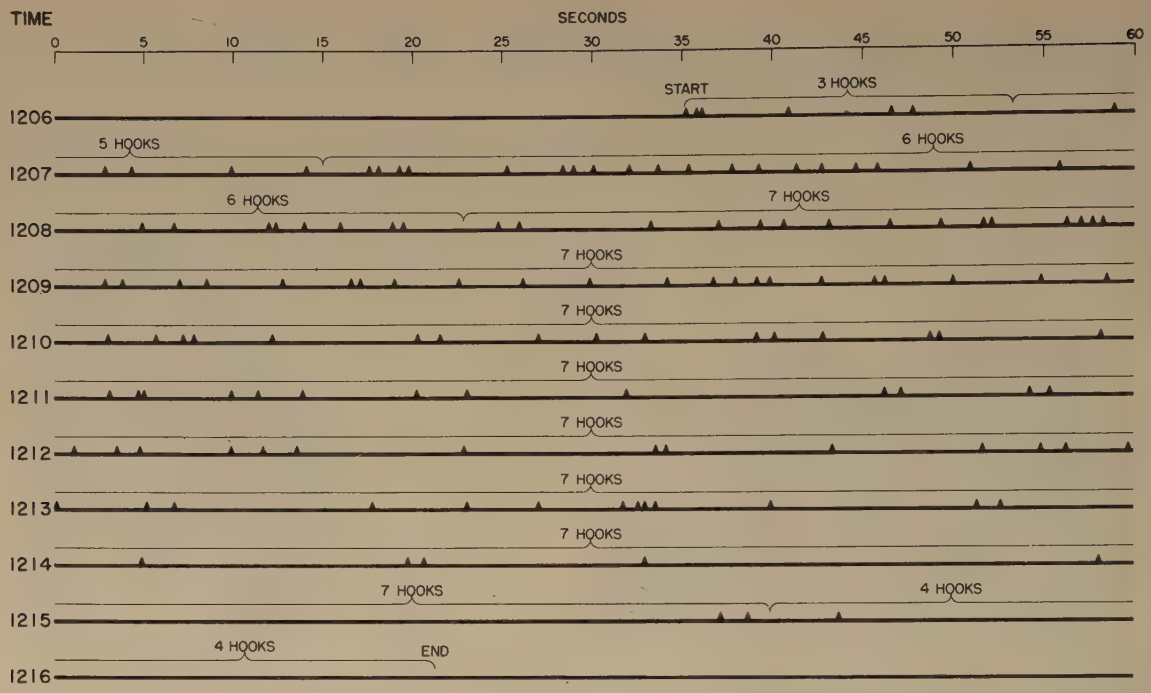


FIGURE 2.—Plot of the landing of individual skipjack, and time. Each mark represents one skipjack.

displacement to the nearest 0.1 ml. or with an error of about 1 percent depending on the volume. In addition, all fish were ranked by relative stage of digestion.

The fork lengths of the smallest and largest fish in each family from each sample of stomachs were measured. This disclosed the size range of each fish family consumed by an individual skipjack school. The lengths of the squid mantles were likewise measured. Linear measurements of other items were not attempted.

Digested remains were identified whenever possible as fish, mollusks, or crustacean. Otherwise they were classified as "gurry." Volumetric measurements were taken as described earlier.

The bait found in stomachs received the same treatment as other fish, but the results were discarded as unreliable because skipjack often regurgitate much of the bait as they are caught or soon after. At times food deeper in the stomach is also regurgitated but the amount seems negligible.

Trematodes, nematodes, and Acanthocephala were found in the stomachs in small quantities. These were assumed to be parasites and were not considered.

RESULTS

GENERAL INFORMATION ON FISHING

No fish were caught from 52 percent of the schools chummed.

The rate at which the skipjack took the hooks varied. More often than not the fish seemed to bite in short flurries (fig. 2). This may be due to the distributional makeup of skipjack schools. In the few times when the fish could be clearly seen in the water, the schools seemed to be aggregates of many small groups of about 10 fish each.

When the catch rates are plotted against elapsed fishing time at 1- or 2-minute intervals (fig. 3), they present an assortment of shapes. In general there is a rise to a peak with a subsequent decline. Figure 3, *A* shows a relatively early peak, with irregular rise and decline and is typical of most of the plots. Occasionally there are variations as seen in figure 3: *B* illustrates a later peak; *C* has a sharper decline; and *D*, the major peak, is not particularly dominant. *E* is an example of a school that responded poorly. An average of 32.7 percent of the total catch was made during the prepeak period.

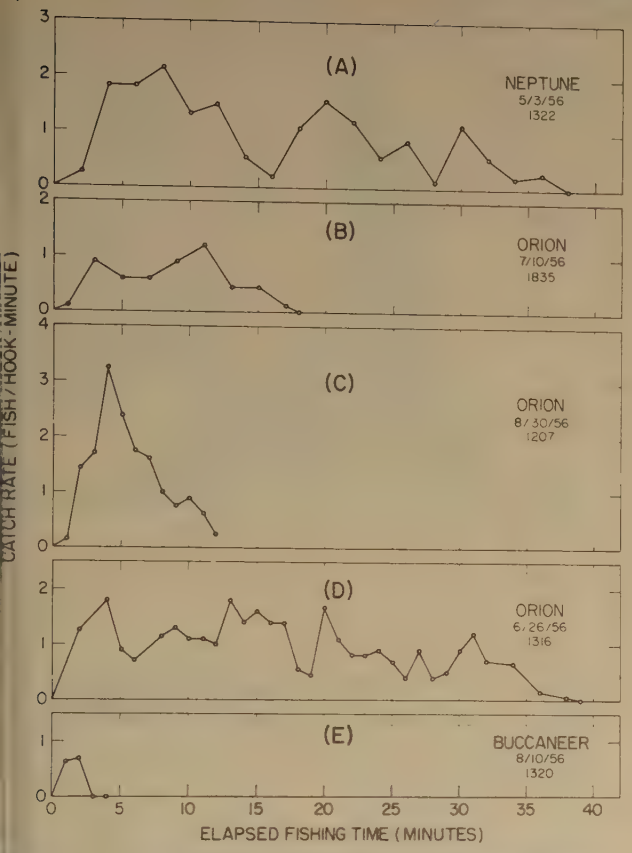


FIGURE 3.—Plots of catch rates against elapsed fishing time. *A*, typical. *B*, late peak. *C*, sharp decline. *D*, no dominant peak. *E*, poor response.

MEASURES OF BITING RESPONSE

Total catch per school is probably the most convenient measure of a school's response to chum. This would be the measure of most interest if it were to be applied toward estimating the fishing potential of a new area. Of the schools observed, the catch per school ranged from 1 to 773. The frequency distributions of catch per school (fig. 4) were not normal. Since the lengths of the fish fell into two distinct groups (fig. 5), the distributions were plotted separately.[2]

However convenient a measure the total catch may be, it is difficult to translate into terms of fish behavior because it is a reflection of a sum of behavioral and non-behavioral factors. We sought a measure of biting response that would be indicative of both behavior and yield. Correlation procedures as described by Snedecor (1946) were applied to the data to determine which of the measures of the fishing operation were associated with total catch. Since most of the frequency distributions of the various measures were skewed and sometimes truncated, Spearman's method of rank correlation was used. Computing a series of correlation coefficients is not condoned because the probability of encountering a significant correlation due to chance is increased. In this and a later section, however, such computations were included in preliminary surveys to gain information on which to base hypotheses and were not used as grounds for acceptance or rejection.

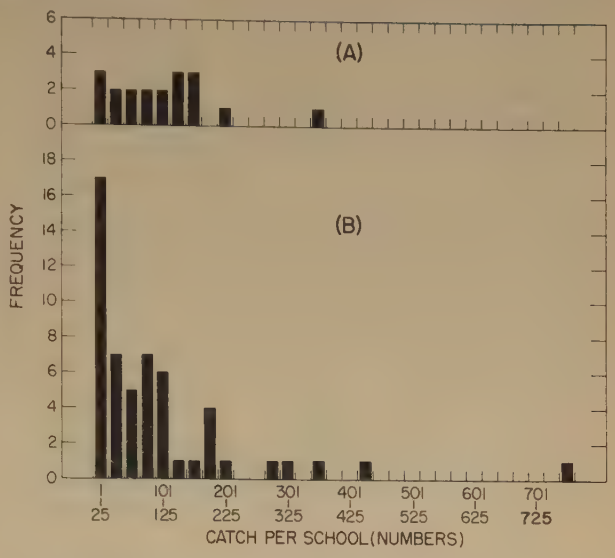


FIGURE 4.—Frequency distributions of catch per school. *A*, represents skipjack smaller than 60 cm. fork length. *B*, represents skipjack greater than 60 cm. fork length.

Fishing duration, which is defined as the time from the introduction of hooks into the water to their final withdrawal, was found to be highly correlated with total catch.[3] The rank correlation coefficient (r_s=0.710**) with 84 degrees of freedom is well beyond the 1-percent level of significance. (In accordance with common practice, 2 asterisks (**) will be used to mark values beyond the 1-percent level of significance and one asterisk (*) to mark values beyond the 5-percent level.) Fishing duration ranged from 1 to 82 minutes. The frequency distributions of fishing

[2] Hereafter the fish will be designated as large or small depending on whether the sample means of fork lengths were more or less than 60 cm., respectively.

[3] Data for this and other procedures are tabulated in the appendix, table 5.

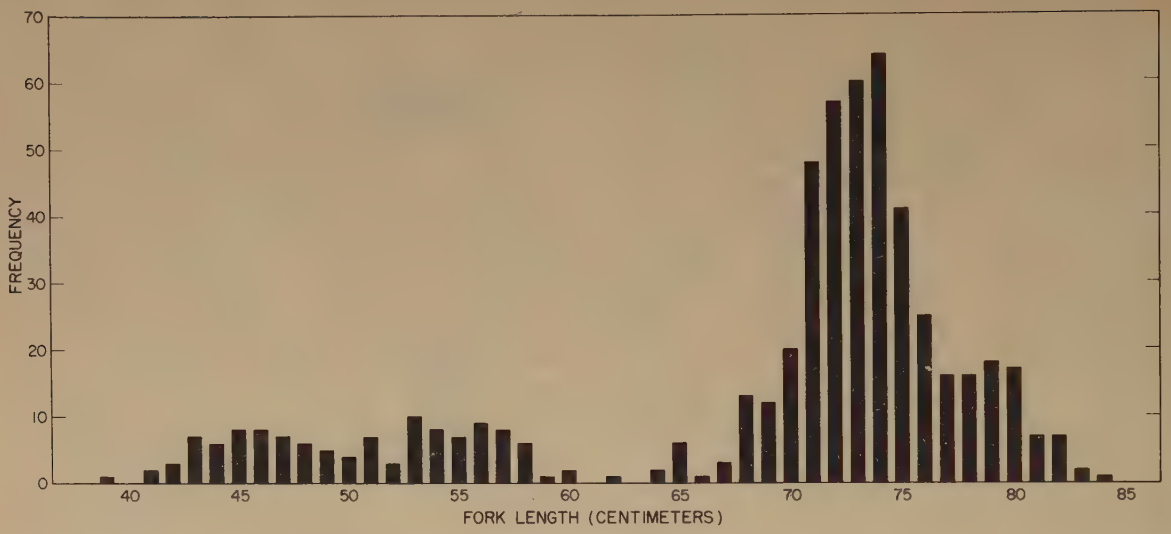


FIGURE 5.—Frequency distribution of fork lengths of skipjack sampled.

duration of small and large fish (fig. 6) does not depict any obvious difference between the two.

The peak catch rate expressed in terms of fish per hook-minute was also found to be significantly correlated with total catch (r_s=0.796**). The range of this variate for both large and small fish is about the same. The frequency distributions of peak catch rates of large and small fish (fig. 7), however, show quite divergent modes. A dominant mode for the large fish lies somewhere between 0.40 and 1.00 fish per hook-minute, while for the small fish the mode seems to be between 3.20 and 3.40 fish per hook-minute. This difference in peak catch rates cannot be attributed entirely to behavioral differences of the two sizes. An undetermined part of the difference is due to the greater ease with which the fishermen land the smaller fish.

The elapsed time from the start of fishing to the peak catch rate (hereafter called prepeak duration) and the time interval from the peak catch rate to the end of fishing or postpeak duration, were also compared with total catch. Postpeak duration and total catch were found to be highly correlated (r_s=0.750**), while the prepeak duration and total catch were not (r_s=0.204). Prepeak duration ranged from 0.5 to 42.5 min-

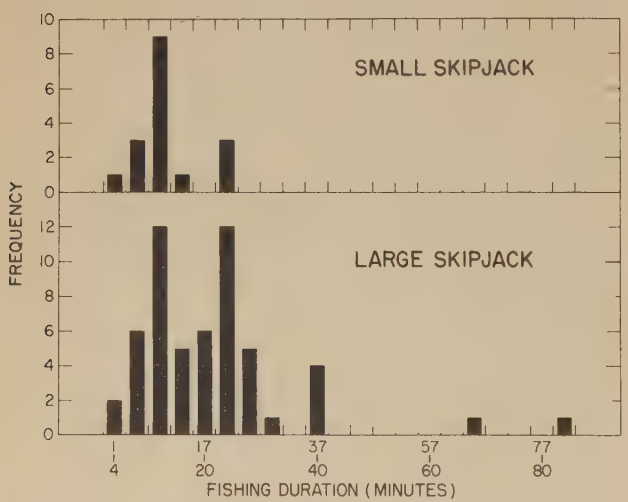


FIGURE 6.—Frequency distributions of fishing duration of large and small skipjack.

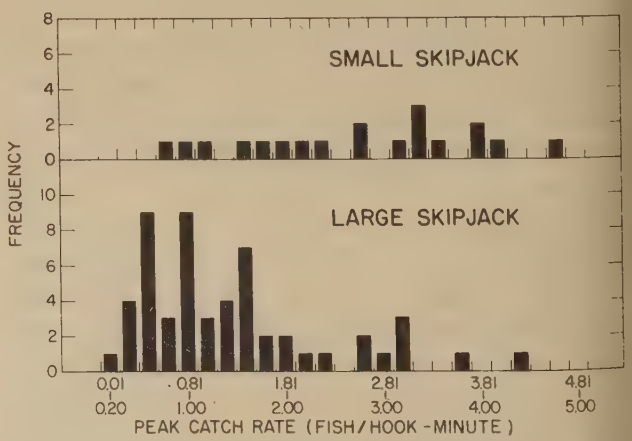
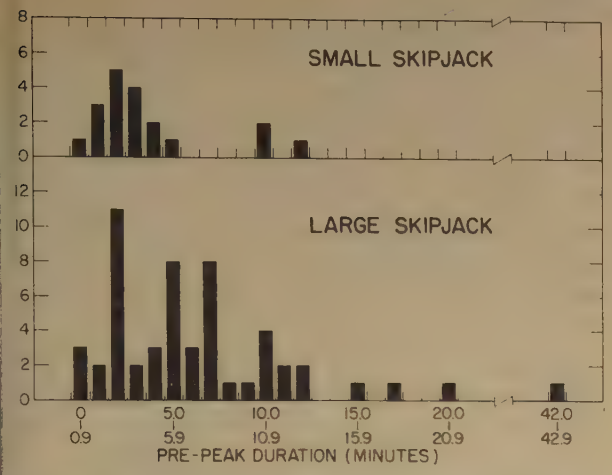


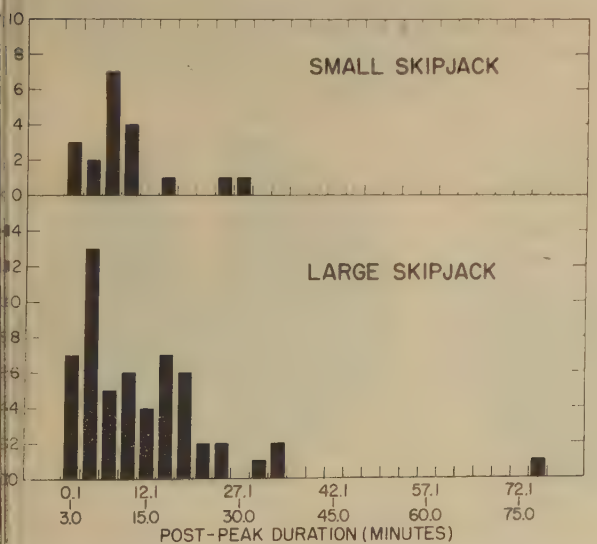
FIGURE 7.—Frequency distributions of peak catch rates for large and small skipjack.



IGURE 8.—**Frequency distributions of prepeak duration for large and small skipjack.**

es (fig. 8) and postpeak duration ranged from to 77 minutes (fig. 9).

The average increase per minute of the prepeak tch rates and the average decrease per minute the postpeak catch rates for each school were mputed by using regression methods with the ssumption that the rates of increase and decrease ere linear. The frequency distributions of these tes, placed into categories of large and small h (fig. 10), show greater skewness in the dis- ibutions for the large fish. Total catch was und to be significantly correlated with the rate



URE 9.—**Frequency distributions of postpeak duration for large and small skipjack.**

of prepeak increase (r_s=0.395**) but not with the rate of postpeak decline (r_s=−0.009).

Another factor that affected the total catch was the mean number of hooks fished per minute. The rank correlation coefficient was 0.259*. The grand mean number of hooks fished was 7.38±1.42.

Total catch did not seem to be influenced by the number of passes needed to stop a school (range 1 to 12 passes) nor the time interval from the start of the successful pass to the start of fishing (range of 0 to 31 minutes). The r_s values were −0.043 and 0.111, respectively.

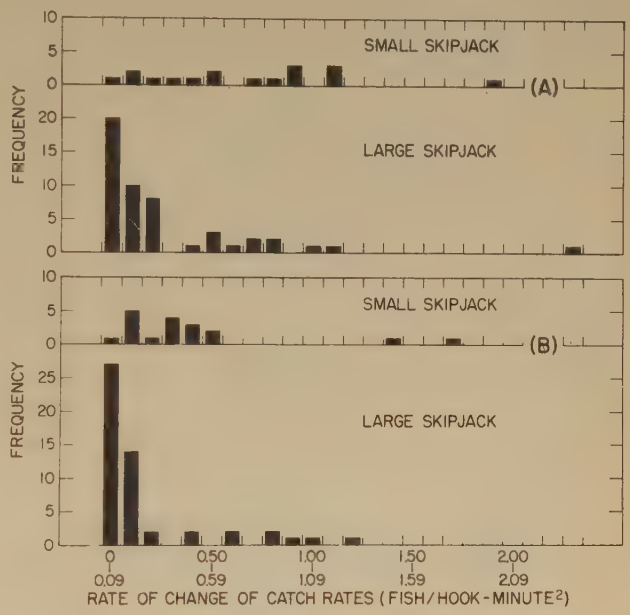


FIGURE 10.—*A*, **Frequency distributions of rate of increase of peak catch rates.** *B*, **Frequency distributions of rate of decrease of postpeak catch rates.**

Summarizing (table 1), the measured factors which seemed to influence the catch were (1) postpeak duration, (2) fishing duration, (3) peak catch rate, (4) mean number of hooks per minute, and (5) rate of increase of prepeak catch rates. Of these the peak catch rate and the postpeak duration were chosen as measures of skipjack response for use in later analyses. These, we thought, would be measures of two different aspects of response to chum. The peak catch rate would measure the degree of interest or intensity of the skipjack in feeding, and the postpeak duration would measure the duration of interest.

This by no means implies that these aspects are separate entities. In fact, the rank correlation coefficient between the two is 0.382** which may be interpreted to mean that factors common to both exist, or that one is influenced by the other.

Another consideration is that these measures may also be associated with school size. It is conceivable that a larger school would result in a longer postpeak duration. Perhaps the fish in a larger school would be more densely distributed which would result in a higher peak catch purely on a mechanical basis. It is also possible that behavior is influenced by school size. Unfortunately these possibilities must remain as conjectures for the present as no means for measuring the school size was available.

TABLE 1.—*Correlation coefficients of total catch with various measures of fishing*

Measure	Degrees of freedom	r
Fishing duration	84	0.772**
Peak catch rate	84	.614**
Prepeak duration	84	.201
Postpeak duration	84	.868**
Rate of prepeak increase	71	.274*
Rate of postpeak decrease	73	−.120
Mean number of hooks	84	.289**
Number of passes	81	−.06
Time from start of pass to start of fishing	79	.01

DESCRIPTION OF STOMACH CONTENTS

For descriptive purposes, the group designated as small fish was further divided into two groups with 50 cm. as the separating point. The volume of the stomach contents varied markedly with fish size. The mean volume for large fish was 35.6 ml./fish. The school means ranged from 2.4 to 154.1 ml./fish. Skipjack 50 to 60 cm. in fork length showed a mean volume of 20.4 ml./fish with school means ranging from 1.5 to 55.6 ml./fish, while skipjack shorter than 50 cm. had a mean volume of 9.1 ml./fish with school means ranging from 1.3 to 15.2 ml./fish.

The food of the skipjack of the different size groups was alike and consisted of fish, mollusks, and crustaceans, but in different proportions. During the fishing season, fish accounted for 91 percent by volume of the large skipjack's diet but contributed less to the food of the smaller skipjack (fig. 11). The percentage compositions of fish in the stomachs of skipjack of 50 to 60 cm. long and skipjack less than 50 cm. long were 70 percent and 40 percent, respectively. On the other hand, mollusks and crustaceans were of relatively increasing importance with a decrease in size.

The six schools sampled during the off season, October 1956 through March 1957, produced somewhat different percentage compositions (fig. 12). Three of the schools were composed of skipjack estimated at 12 to 13 pounds and the other three consisted of skipjack estimated at 22 pounds. All of these fish would be classified as large. The percentage of fish in the stomachs was 59 percent as compared to 91 percent found during the season.

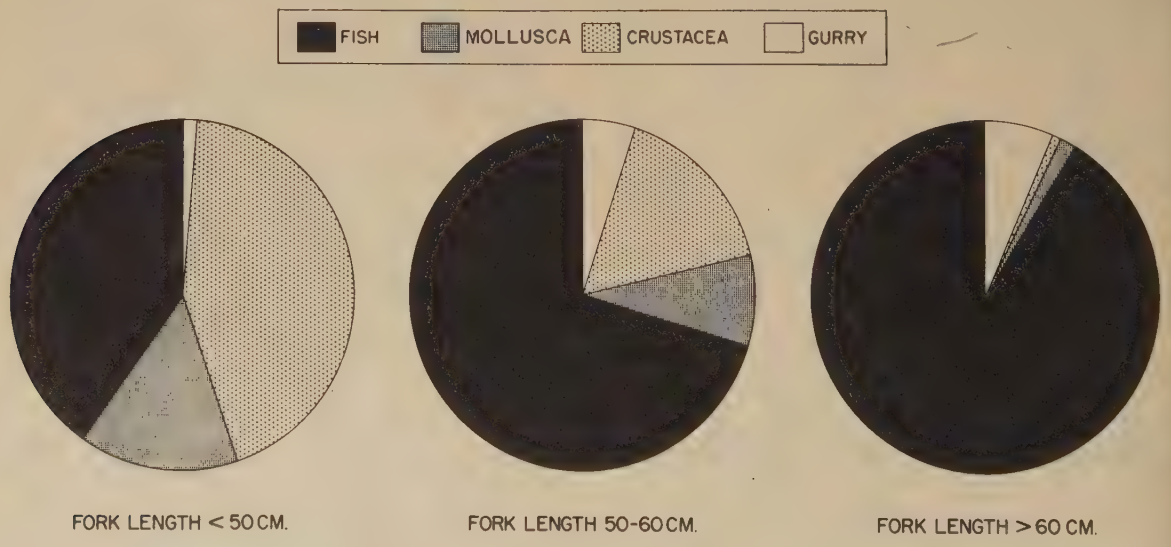
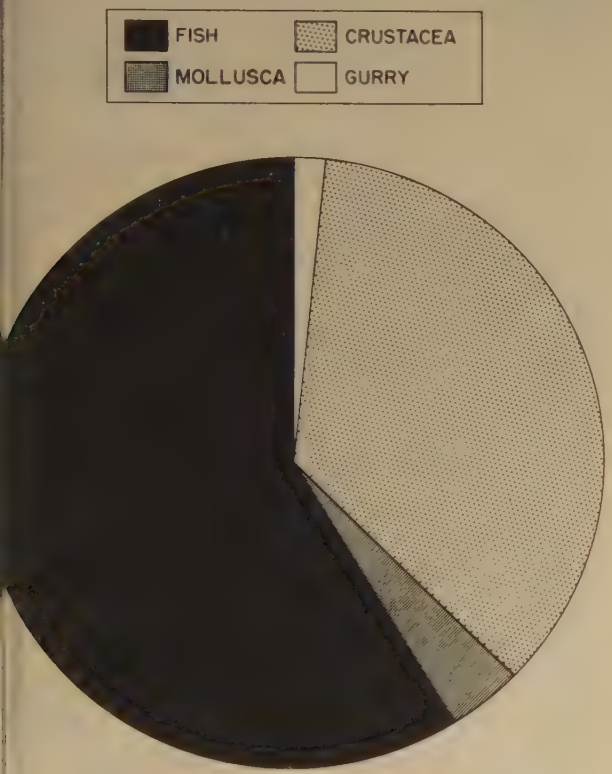


FIGURE 11.—Diagrams illustrating the composition by volume of the stomach contents of three sizes of skipjack caught during the fishing season.

nother difference between the diets of season and onseason skipjack was the percentage of crustaeans. The figures are 36 percent for nonseason kipjack and less than 1 percent for season skipack.

Representatives of 30 fish families and a few nidentified fish were found in the stomach conents. The families are listed in table 2 in order f percentage of total mean volume. The percentges listed are for fishes of the season and were lculated in the following manner to compensate



GURE 12.—Diagram illustrating the composition by volme of stomach contents of large skipjack caught during the off season.

r the difference in sample sizes. First, the mean lume of each category in units of ml./stomach s taken for each school. Then the total mean lume of each category was divided by the grand al mean volume and converted to percentages. this way the contents from each school were ven equal weight regardless of sample size. rangids (genus *Decapterus*) were by far the ost important item in terms of both volume and currence. The genus *Cubiceps* of the family omeidae also contributed considerably to the volumes. Gurry, a small piece of wood, and a cigarette butt were classed under miscellaneous.

FACTORS INFLUENCING BITING RESPONSE

As selected in a previous section, peak catch rate and postpeak duration were used as measures of biting response. These were compared with a number of possible factors by correlation procedures or by plotting.

TABLE 2.—*Stomach contents of skipjack from 34 schools*

Contents		Percentage of total mean volume	Occurrence (number of schools)
Fish	Carangidae	45.01	27
	Nomeidae	20.25	10
	Molidae	6.45	6
	Thunnidae	3.14	13
	Gempylidae	2.27	19
	Sudidae	1.53	1
	Holocentridae	1.04	11
	Chaetodontidae	.92	21
	Bramidae	.59	10
	Scorpaenidae	.28	15
	Mullidae	.13	4
	Acanthuridae	.11	9
	Balistidae	.11	7
	Sphyraenidae	.10	1
	Exocoetidae	.07	2
	Serranidae	.06	1
	Diodontidae	.05	1
	Synodontidae	.04	4
	Priacanthidae	.03	2
	Blenniidae	.02	3
	Ammodytidae	.02	3
	Fistularidae	.01	2
	Antigonidae	.01	1
	Cirrhitidae	.01	2
	Dactylopteridae	.01	2
	Ostraciidae	.01	4
	Syngnathidae	Trace	1
	Pomacentridae	Trace	1
	Tetrodontidae	Trace	1
	Pegasidae	Trace	1
	Unidentified fish	.42	20
Mollusks	Decapoda	2.28	24
	Octopoda	.02	1
Crustacea	Stomatopoda	2.51	24
	Decapoda	.94	23
	Amphipoda	.08	7
	Isopoda	Trace	5
	Euphausiacea	Trace	1
Miscellaneous		11.49	34

SKIPJACK SIZE

The mean length of the skipjack for each school was found to be significantly correlated with peak catch rate ($r_s = -0.475^{**}$). As mentioned earlier, this is at least in part attributed to the greater facility with which the small fish were landed. Correlation between mean length and postpeak duration ($r_s = -0.058$) was not significant.

HUNGER AND TIME SINCE LAST MAJOR FEEDING

The mean volume of the stomach contents (ml./stomach) for each school was used as a measure of the state of hunger. The time since the last

major feeding was expressed by the lowest stage of digestion found in the dominant fish family or families in the stomach contents of a school, using the following criteria:

Stage 1. Fish intact.
Stage 2. Skin or head missing.
Stage 3. Part of flesh missing
Stage 4. Skeletal remains.

Since the rate of digestion is not known, this measure is a relative one. Only the large skipjack caught during the season provided sufficient data for this study.

Since the stage of digestion was found to be highly correlated with the mean volume ($r_s = -0.607^{**}$), partial correlation procedures (Snedecor 1946) were used to assess the relations of these variates to biting response. Although the variates did not meet the assumption of normality, we found no other satisfactory technique and thought that these relations should be investigated.

The peak catch rate was not significantly correlated with either variate. This is in contrast to the findings of Uda (1933) and Suyehiro (1938). The former stated that skipjack with stomachs between the extremes of fullness and emptiness tended to respond more poorly to fishing when their stomachs were emptier. The latter observed that skipjack which had fed recently did not bite so well as those that were hungry. His measure of the recentness of feeding was the depth of the rugae; i.e., a smooth stomach lining indicated recent feeding. We suspect, however, that the depth of the rugae is directly related to the state of distention of the stomach, which depends upon the amount of food in it.

Multiple correlation computations of postpeak duration with stage of digestion and mean volume resulted in $R = -0.565^{*}$. In further computations, the partial correlation coefficient between postpeak duration and stage of digestion, independent of mean volume, was found to be -0.535^{*} and that between postpeak duration and mean volume, independent of stage of digestion, was found to be -0.506^{*}. That is to say, the postpeak duration was longer when the major items in the stomachs were in the earlier stages of digestion and the stomachs were emptier.

From this we hypothesize that live-bait fishing techniques employed in Hawaii generally do not create a state of feeding excitement in the skipjack, but exploit an already existing one which apparently is caused by the presence of natural food. The fact that less than one-half of the schools respond to chum supports the hypothesis. Furthermore, the correlations infer that the state of excitement diminishes with feeding or with time if the skipjack were not satiated when the natural food became unavailable.

PREY BEHAVIOR

In order to determine whether any association existed between prey behavior and biting behavior of skipjack, schools were grouped according to families of fish in their stomachs. Only first and second stages of digestion were considered, and, if a school of fish had representatives of several families, the school was tabulated in each family classification. The mean peak catch rate and mean postpeak duration for each group represented by four or more schools were computed. As an example, the mean peak catch rate and the mean postpeak duration were calculated for all schools with the family Carangidae in the first and second stages of digestion.

The families are listed in tables 3 and 4 in descending order of their means. If the families were classified by their swimming abilities, the

TABLE 3.—*List of fish families and peak catch rate means*

Family	Mean peak catch rate (fish/hook-minute)
Nomeidae	1.92
Thunnidae	1.55
Carangidae	1.51
Gempylidae	1.47
Chaetodontidae	1.43
Scorpaenidae	1.31
Molidae	1.30
Acanthuridae	1.17

TABLE 4.—*List of fish families and postpeak duration means*

Family	Postpeak duration (minutes)
Nomeidae	17.7
Thunnidae	17.5
Gempylidae	17.4
Scorpaenidae	16.4
Acanthuridae	15.8
Carangidae	15.3
Molidae	14.1
Chaetodontidae	12.8

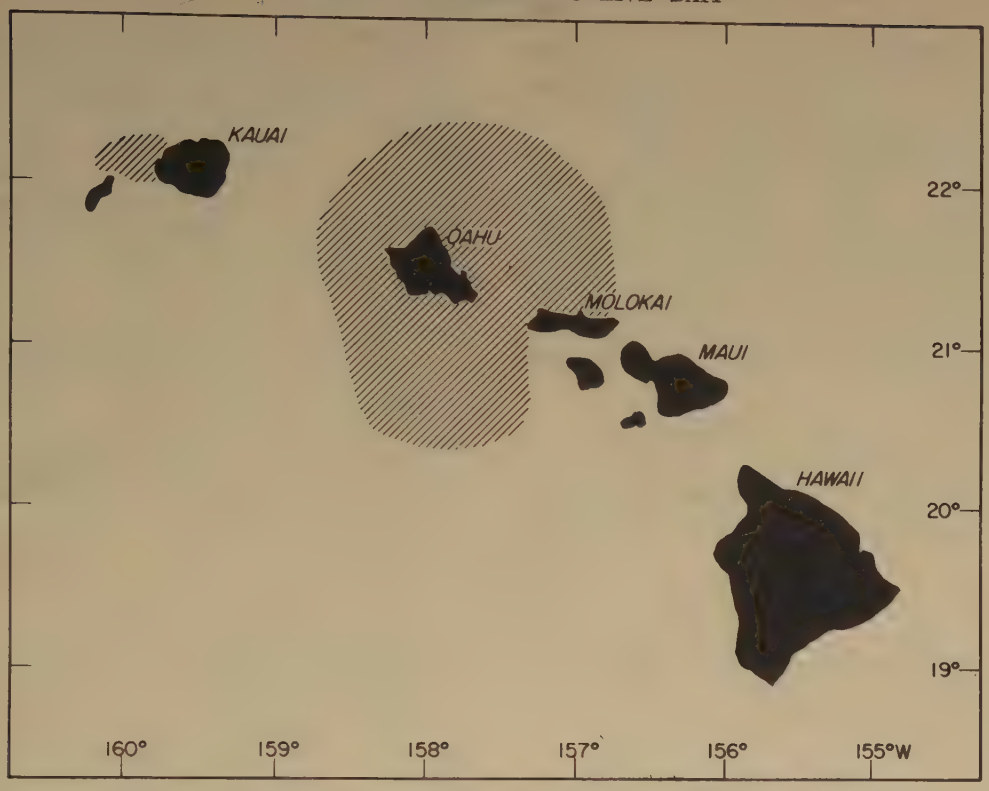


FIGURE 13.—Chart showing the areas of fishing where observations were made.

st swimmers would include the families Thun-dae, Carangidae, Gempylidae, and Nomeidae, nile the remainder would be considered slow immers. The fast swimmers are in the top ur positions of table 3 and in the top three posi-ns of table 4. It therefore appears that skip-k feeding on fast-swimming fish exhibit a more vorable biting behavior than skipjack feeding slow-swimming fish.

STATE OF OVARY DEVELOPMENT

The ovaries collected from the large skipjack re all maturing. A few of the eggs were teased m the group of largest eggs in each ovary, and diameters of five were measured. The great-diameter found in each school was used as a gh measure of maturity. The correlations of diameters with peak catch rate (r_s=0.086) l postpeak duration (r_s=0.258) were not sig-cant. The absence of ripe skipjack in the ch may be due to the reluctance of such skip-k to feed, but the stages of egg maturation er than ripeness do not appear to affect biting ponse.

LOCATION

All observations were made in the regions represented by the shaded areas in figure 13. The shaded area at the west end of the island of Kauai represents only one trip. The rest of the trips were within the shaded area around the island of Oahu.

The peak catch rate for large fish showed a positive significant correlation with distance from land (r_s=0.308*). For small fish, the correlation was not significant (r_s=0.057). No significant correlation was found between postpeak duration and distance from land for either large or small fish (r_s values of −0.040 and −0.224, respectively).

TIME OF DAY

Examination of peak catch rate, postpeak duration, and the percentage of schools successfully fished relative to time of day indicated no relation. Data on the Japanese skipjack fishery (Uda 1940a) show that catches were highest between 6 a.m. and 8 a.m., but the peak was not reflected in the catch rates. Suyehiro (1938) stated that fishing was best during early morning but provided no data.

WEATHER CONDITIONS

The weather conditions were predominantly uniform and biting behavior did not change on the unusual days. The height of the sea ranged from 1 to 10 feet, with 2 to 5 feet being the usual condition. Estimations of wind velocity ranged from 0 to 30 knots, but most of the estimates were between 10 and 20 knots. Most of the days were bright and sunny. The few darker days affected fishing only in decreasing the chances of sighting schools.

SUMMARY AND CONCLUSIONS

Commercial fishing of 92 skipjack schools was observed and resulted in the following information:

1. Fifty-two percent of the schools chummed yielded no fish.

2. The number of fish caught per school varied from 1 to 773.

3. Total fishing time per school varied from 1 to 82 minutes.

4. The number of passes required to stop a school varied from 1 to 12.

5. The mean number of hooks fished per school was 7.38 ± 1.42.

6. Although the catch rate varied during fishing operations, the general tendency was to rise to a peak and then decline with elapsed fishing time.

7. The peak catch rate ranged from 0.12 to 4.29 fish per hook-minute for large skipjack (fork length greater than 60 cm.) with a mode of 0.40 to 1.00 fish per hook-minute, while small skipjack (fork length less than 60 cm.) had a range of 0.75 to 4.62 fish per hook-minute with a mode of 3.20 to 3.40 fish per hook-minute.

8. The prepeak duration ranged from 0.5 to 42.5 minutes with a mode of 2 to 3 minutes.

9. The postpeak duration ranged from 0 to 77 minutes with a mode of 3 to 6 minutes.

10. The catch per school was affected by fishing duration, postpeak duration (which is part of fishing duration), peak catch rate, number of hooks fishing, and the rate of increase of prepeak catches.

Examination of the contents of 573 stomachs representing 49 schools revealed the following:

1. The mean volumes of stomach contents for skipjack of fork length greater than 60 cm., 50 to 60 cm., and less than 50 cm. were 35.6 ml., 20.4 ml., and 9.1 ml., respectively.

2. The percentage of fish in the stomachs collected during the fishing season decreased with a decrease in skipjack size while the percentages of mollusks and crustaceans increased.

3. The percentage of fish in the stomachs of large skipjack caught during the off season was less than that of those caught during the season. The reverse was true of the percentage of crustaceans.

4. The fish contributing most to the diet of skipjack were the genus *Decapterus*, of the family Carangidae, and the genus *Cubiceps*, of the family Nomeidae.

5. Representatives of more than 30 families of fish were found in the stomachs.

A study of the causal factors of the variation in biting response showed that—

1. Large skipjack tended to take the hooks faster the farther away they were from land.

2. The duration of response to chum was negatively correlated with mean stomach volumes and the stage of digestion of the dominant component of the stomach contents.

3. Skipjack feeding on fast-swimming fish were caught at a faster rate and fished for a longer period than those feeding on slow-swimming fish.

4. The relation between the state of ovary development and biting response is not clear, but only skipjack in the maturing stage were caught. In the maturing stage there was no correlation between biting response and a slight gradient in egg development.

5. Biting response was not affected by the time of day or weather conditions.

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APPENDIX

Data from schools fished during skipjack season

[Data from 6 schools fished in competition with other boats are not listed]

ate	Starting time	Total catch	Number of passes needed to stop school	Prepeak duration (minutes)	Postpeak duration (minutes)	Fishing duration (minutes)	Mean number of hooks fished (hooks/minute)	Peak catch rate (fish/hook-minute)	Rate of increase of pre-peak catch rates (fish/hook-minute)	Rate of decrease of post-peak catch rates (fish/hook-minute)	Distance from land (miles) [1]	Fish size [2]	Mean volume of stomach contents (ml./stomach)	Lowest stage of digestion of major components
56														
3	1036	5	2	10.5	0.5	11	6.5	0.50	0.02	----------	----------	B	----------	----------
3	1322	280	1	7.0	31.0	38	7.9	2.17	.28	0.045	----------	B	----------	----------
8	1453	49	1	7.0	7.0	14	7.7	.88	.10	.125	30 W	B	----------	----------
8	1614	11	1	5.0	4.0	9	7.3	.42	.27	.124	----------	B	----------	----------
8	1630	47	1	15.0	6.0	21	6.9	.75	.03	.104	----------	B	----------	----------
8	1805	81	7	3.0	4.0	7	8.3	2.25	.62	.689	----------	B	----------	----------
15	0815	87	1	5.0	12.0	17	8.8	1.15	.18	.061	20 L	B	----------	----------
15	0900	66	3	5.0	16.0	21	8.1	1.06	.21	.068	20 L	B	----------	----------
16	1538	15	1	7.0	17.0	24	7.6	.29	.02	.014	18 L	B	----------	----------
21	0845	197	1	0.5	20.5	21	9.7	3.62	----------	.094	10 W	B	----------	----------
21	1203	47	1	1.0	13.0	14	9.1	0.75	----------	.065	15 W	----------	----------	----------
21	1412	773	1	5.0	77.0	82	9.7	3.18	.78	.031	20 W	B	18.6	1
26	1242	118	1	7.0	17.0	24	10.0	1.45	.16	.050	30 W	B	32.5	2
26	1316	355	1	3.0	36.0	39	9.9	1.80	.28	.032	30 W	B	14.1	3
26	1459	44	1	4.5	5.5	10	9.4	.89	.16	.114	30 W	B	----------	----------
26	1522	245	1	3.5	23.5	27	9.0	1.89	.50	.038	30 W	----------	----------	----------
26	1629	140	1	6.0	15.0	21	6.0	2.50	.42	.139	25 W	----------	----------	----------
29	1112	4	2	5.0	4.0	9	7.3	.12	.03	.034	----------	B	154.1	1
29	1142	104	1	9.0	13.0	22	9.0	1.20	.14	.084	----------	B	----------	----------
29	1613	110	1	7.0	18.0	25	7.8	1.50	.27	.052	----------	B	54.3	2
3	0910	79	2	12.0	12.0	24	7.5	1.00	.03	.041	10 W	B	41.6	2
4	1002	58	1	2.0	21.0	23	6.8	.69	.28	.019	10 W	B	41.6	1
4	1204	66	4	10.0	11.0	21	7.7	1.92	.14	.148	6 W	B	101.8	1
10	0907	54	2	2.0	16.0	18	9.0	1.22	.56	.044	15 W	B	22.6	2
10	0950	79	1	2.0	10.0	12	9.2	1.28	.59	.111	15 W	B	----------	----------
10	1002	32	1	2.0	10.0	12	8.2	.50	.18	.070	15 W	B	----------	----------
10	1116	106	3	7.0	16.0	23	8.9	1.50	.11	.089	6 W	B	9.1	2
10	1835	90	5	10.0	8.0	18	8.7	1.21	.08	.153	5 W	B	----------	----------
17	0824	4	3	6.0	.0	6	10.3	.22	.04	----------	10 W	B	----------	----------
17	1146	244	2	12.0	27.0	39	8.4	1.56	.09	.040	12 W	B	74.0	2
19	0811	39	1	8.0	5.0	13	6.2	.92	.08	.200	18 L	B	2.4	3
19	1245	140	12	7.0	14.0	21	6.7	1.83	.02	.121	50 L	B	5.7	3
19	1352	94	1	2.0	18.0	20	6.0	1.56	.71	.064	60 L	----------	----------	----------
24	1130	8	1	5.0	4.0	9	7.0	.21	.03	.065	10 L	B	37.3	2
24	1721	120	7	7.0	20.0	27	6.7	1.50	.20	.040	5 L	B	30.0	1
25	0916	6	4	5.0	2.0	7	6.0	.42	.14	.420	20 L	B	----------	----------
25	1602	12	5	5.0	5.0	10	6.0	.50	.09	.125	15 L	B	----------	----------
26	0734	23	1	11.5	5.5	17	7.8	.38	.01	.063	15 L	B	----------	----------
26	0918	43	1	17.5	12.5	30	7.4	.83	.01	.038	10 L	B	----------	----------
26	1248	51	1	20.5	5.5	26	7.0	.60	.01	.153	8 L	B	----------	----------
27	1003	165	1	42.5	22.5	65	6.0	1.40	.00	.041	10 L	B	----------	----------

ee footnotes at end of table.

Data from schools fished during skipjack season—Continued

Date	Starting time	Total catch	Number of passes needed to stop school	Prepeak duration (minutes)	Postpeak duration (minutes)	Fishing duration (minutes)	Mean number of hooks fished (hooks/minute)	Peak catch rate (fish/hook-minute)	Rate of increase of prepeak catch rates (fish/hook-minute)	Rate of decrease of postpeak catch rates (fish/hook-minute)	Distance from land (miles) [1]	Fish size [2]	Mean volume of stomach contents (ml./stomach)	Lowest stage of digestion of major components
1956														
Aug. 8	1221	30	4	2.5	9.5	12	5.6	1.67	1.17	0.171	30 L	B	18.6	3
9	0942	10	2	6.5	1.5	8	7.0	0.86	.09	.860	20 L	B	106.2	2
10	0810	35	3	2.5	4.5	7	6.9	1.83	1.16	.466	2 W	S	4.7	
10	1134	21	4	1.5	5.5	7	6.4	.92		.103	¾ W	S	1.3	
10	1320	12	1	1.5	1.5	3	8.7	.70			50 L	B		
22	1025	3	3	.5	1.5	2	7.0	.50			40 L	B	11.0	3
30	1207	123	9	3.5	8.5	12	7.8	3.25	.96	.332	30 L	S	15.1	
30	1331	171	3	3.5	8.5	12	7.5	4.00	.99	.294	30 L	S	22.6	
30	1407	19	1	2.5	2.5	5	7.2	1.14	.50	.570	30 L	S	20.7	
30	1440	139	1	11.5	18.5	30	7.2	1.75	.05	.071	25 L			
Sept. 12	0930	113	3	2.0	4.0	6	8.8	3.06	1.03	.630	30 L	B	9.2	3
12	0956	82	2	11.5	8.5	20	6.8	1.57	.03	.115	30 L	B		
1957														
May 23	0750	52	2	2.5	.5	3	6.7	3.12			10 W			
23	0832	2	1	.5	.5	1	5.0	.40			20 W			
23	0846	13	1	1.5	.5	2	5.0	2.20			20 W			
23	0912	17	1	1.5	.5	2	6.0	2.14			20 W			
23	1301	22	3	2.5	5.5	8	6.9	1.00	.50	.123	20 W	B	4.5	3
23	1612	189	11	1.5	21.5	23	6.9	2.80	2.30	.109	25 W	B		
June 13	1207	128	1	2.5	7.0	10	6.4	3.29	.58	.382	20 W	S	15.2	
19	1007	19	4	.5	8.5	9	8.6	.88		.041	10 W	B		
19	1023	19	1	4.5	8.5	13	7.5	.44	.09	.038	15 W	B	33.7	2
19	1222	23	3	10.5	2.5	13	7.4	1.00	.02	1.000		B		
19	1343	94	4	6.5	18.5	25	7.7	1.50	.18	.050	20 W	B	9.4	2
July 3	0950	111	5	10.5	10.5	21	5.6	4.62	.30	.189	3 W	S	3.3	
3	1040	358		2.5	25.5	28	7.2	4.00	1.12	.156	20 L	S	11.0	
3	1207	142		2.5	9.5	12	7.2	3.50	.95	.445	20 L	S		
3	1228	67	1	3.5	6.5	10	6.9	2.71	.81	.385	25 L	S		
3	1317	71	1	3.5	9.5	13	7.2	1.57	.15	.113	30 L	S		
3	1353	207	1	12.5	8.5	21	7.3	3.38	.02	.405	30 L	S		
3	1430	83	1	4.5	6.5	11	7.7	1.62	.25	.296	30 L	S		
3	1510	95	1	10.5	1.5	12	6.8	2.71	.11	1.700	30 L	S		
3	1528	6	1	.5	1.5	2	5.0	.75			30 L	S		
3	1552	41		1.5	10.5	12	6.6	2.12	1.12	.140	30 L	S		
Aug. 1	1543	188	1	2.5	16.5	19	6.9	3.00	.72	.196	40 W	B	7.3	
1	1610	431	1	2.5	35.5	38	6.7	4.29	.86	.090	40 W	B		
1	1747	2	2	.5	1.5	2	7.0	.29			40 W			
1	1753	337	1	10.5	14.5	25	6.9	3.57	.21	.233	40 W			
6	0626	157	1	4.5	27.5	32	7.9	2.33	.47	.031	1½ L	S	31.8	
14	0941	84	1	2.5	16.5	19	5.8	3.00	1.50	.103	30 L			
14	1007	15	2	2.5	12.5	15	6.5	.43	.22	.004	20 L	B	23.5	2
14	1806	158	1	5.5	15.5	21	6.9	3.14	.71	.172	10 L	S	55.6	
21	1353	133	2	1.5	7.5	9	7.6	4.14	1.94	.579	55 L	S	1.5	
21	1603	178	1	4.5	5.5	10	7.5	3.12	.44	.403	40 L	B	214.1	1
21	1706	13	4	2.5	0.5	3	5.0	1.40			40 L			
21	1734	315	1	2.5	25.5	28	7.7	2.71	.86	.069	40 L	B		

[1] W=Windward. L=Leeward.
[2] B=mean length > 60 cm. S=mean length <60 cm.